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AUTHOR Duthie, Pamela Rae
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ABSTRACT

To determine the effects of water exercise on the movements of multiple sclerosis patients, this study utilized tests to determine changes in the linear range of motion of the shoulder, elbow, and wrist after a 45-minute period of water activities and to determine if the movement became more effective. The test used was an overhead throw with a 13-inch ball, and involved three subjects--two female and one male. The findings showed that, except for the horizontal motion of the shoulder, range of motion, force production, and horizontal ball velocity increased. (DS)

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CHANGES IN UPPER EXTREMITY RANGE OF MOTION AND
EFFICIENCY IN MULTIPLE SCLEROSIS PATIENTS DUE TO WATER ACTIVITY

BY

PAMELA RAE DUTHIE

Pullman, Washington

1977

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TABLE OF CONTENTS

Acknowledgements.....	ii
List of Figures.....	
List of Graphs.....	vi
List of Appendices-Tables.....	vii
Introduction.....	1
The Problem.....	2
Procedure.....	4
Review of Literature.....	6
Etiology of Multiple Sclerosis.....	6
Therapeutic Exercise.....	9
Shoulder Motion.....	9
Overarm Throw.....	10
Changes in Movement in MS Patients Due to Exercise.....	10
Interpretation of Data.....	11
Subject 1.....	11
Throw 1.....	11
Throw 2.....	14
Throw 3.....	18
Throw 4.....	22
Comparison by throw..	25
Subject 2.....	33
Throw 1.....	33
Throw 2.....	37

TABLE OF CONTENTS (cont)

Throw 3.....	44
Throw 4.....	46
Comparison by throw... ..	52
Subject 3.....	60
Throw 1.....	60
Throw 2.....	65
Comparison by throw.....	70
Cross Subject Comparisons and Statistical Results.....	79
Average Force During Power Phase.....	79
In Flight Horizontal Ball Velocities.....	79
Horizontal Shoulder Displacement.....	80
Vertical Shoulder Displacement.....	80
Horizontal Elbow Displacement.....	81
Vertical Elbow Displacement.....	81
Horizontal Wrist Displacement.....	82
Vertical Wrist Displacement.....	82
Summary and Conclusions.....	83
Findings.....	84
Conclusions.....	85
Appendices.....	86
Bibliography.....	235

LIST OF FIGURES

The figures are line drawings of various positions in each of the throws.

Figure		Page
1.	Subject One	28
2.	Subject Two	55
3.	Subject Three	74

LIST OF GRAPHS

All graphs show displacement in inches.

Graph		Page
I.	Subject 1 Throws 2 and 3	
A.	Ball	29
B.	Shoulder	30
C.	Elbow	31
D.	Wrist	32
II.	Subject 2 Throws 1 and 4	
A.	Ball	56
B.	Shoulder	57
C.	Elbow	58
D.	Wrist	59
III.	Subject 3 Throws 1 and 2	
A.	Ball	75
B.	Shoulder	76
C.	Elbow	77
D.	Wrist	78

CHANGES IN UPPER EXTREMITY RANGE OF MOTION AND
EFFICIENCY IN MULTIPLE SCLEROSIS PATIENTS DUE TO WATER ACTIVITY

CHAPTER I

INTRODUCTION

At the time of this study, an aquatics program for persons with Multiple Sclerosis (MS) had existed at Washington State University for approximately two years. The on going program is staffed by student volunteers from many disciplines including business administration, education, premedical, prephysical therapy, and therapeutic recreation and by professionals in physical education. Many of the volunteers work with the program for several semesters helping to provide a continuity to each client's program.

As each client has a different degree of affliction and as the disease itself is characterized by unpredictable highs and lows in motor ability, goals are established by personal desires and by current potential. Each program, though relatively consistent, may be modified greatly on a day when the client feels particularly weak or when the joints are particularly tight. The clients are intelligent and verbalize freely concerning those activities which do or do not seem beneficial to them. Two-thirds of the clients are female and almost all are wheelchair bound.

During the regular school year, the program provides one session of approximately forty-five minutes of aquatic activity per week. During the summer, the program provides two sessions of approximately seventy-five minutes each.⁽¹⁾ The majority of the clients participate in all sessions unless ill or out of town. A small number of the clients participate on an irregular basis.

Those who participate on a regular basis have mentioned increased mobility after most pool sessions. This increase seemed to occur even if the individual were having a bad day. The volunteers and professionals working with the program also noted the apparent improvement in performance. The author was interested in quantifying this change if it actually did exist.

THE PROBLEM

Purpose of the Study

The purpose of the study was to determine if there were a change in the linear range of motion of the shoulder, elbow, and wrist and to determine if there were a change in efficiency of movement in MS patients following water activity.

Statement of the Problem

The problem was to test change in linear range of motion of the shoulder, elbow, and wrist and to test change in efficiency of motion. The motor skill employed to test these parameters was the overhand throw.

The study was conducted in order to determine if what was apparently observed was in fact true. The hypothesis which was tested at the $\alpha = .05$ level was H_0 : Multiple Sclerosis patients do not show

(1) The study was conducted in the spring.

a change in upper extremity range of motion and efficiency following water activity. The alternate hypothesis was H_a : Multiple Sclerosis patients do show a change in upper extremity range of motion and efficiency following water activity.

CHAPTER II

PROCEDURE

The subjects were not selected at random but were chosen for the following reasons: 1) all wheelchair bound; 2) male-female ratio same as that of group; 3) subject one--good range of motion in shoulder girdle; 4) subject two--structural defects as a result of MS; and 5) subject three--male who had been working with the same volunteer for an extended period.

The subjects were filmed on the pool deck immediately preceding and following the normal aquatic program. Landmarks at the shoulder, elbow, and wrist were indicated by bands of adhesive tape.⁽¹⁾ A forty-eight inch measuring stick was used for a scale. Filming was done using a LoCam Camera with a three factor shutter and a frame rate of fifty frames per second. The camera was four feet high and was fifty-one feet from the subjects. Lighting was provided by windows located behind the subjects at right angles to the camera plane and by two quartz halogen lamps. One lamp was to the right and slightly behind the subject and the other was to the right and slightly in front of the subject. The background was a tile wall.

A .515 pound softball with a circumference of thirteen inches was used. Each subject was given a number of practice throws before the

(1) Subjects were remarked after the water session as the adhesive did not hold up well in the water and caused some subject discomfort.

pression trials. This was done to help eliminate practice effect from the postsession trials and to assure that the subjects were reasonably comfortable with the task.

Preliminary analysis of the film was done using tracings of 1) the ball at the beginning of the power phase, 2) the ball at release, and 3) the ball through the major portion of its flight. A Recordak was used to project the film for the tracings. To provide a check both the diameter of the ball and the forty-eight inch stick were used as scales. Horizontal and vertical displacements were measured and converted to real distances according to the scales. Average force during the power phase and ball velocity (horizontal, vertical, and linear) during flight were computed. On the basis of the preliminary findings it was determined that differences did exist and that further analysis would be profitable.

The film was digitized on a Graphic Tablet using every toher frame. The data was used to compute displacement of the ball, shoulder, elbow, and wrist from the early stages of the throw⁽³⁾ through three to five frames after release. The first and second derivitives were computed to obtain velocity and acceleration respectively.

(3) Analysis was not done when the ball was not visible above the arm of the chair or when there was a great deal of early movement within a confined area.

CHAPTER III

REVIEW OF LITERATURE

Etiology of Multiple Sclerosis

Multiple Sclerosis, a chronic, debilitating disease of the central nervous system usually appears between the ages of twenty and forty. It is a demyelinating disease which is approximately 1.5 times more prevalent in women than in men.⁽¹⁾ "MS is characterized by numerous areas of demyelination and a wide variety of neurological symptoms which have a tendency toward remission and exacerbation."^(2,3)

Clinical types of Multiple Sclerosis

1. "Disseminated-recurrent" Patients with a history of remissions and relapses who show evidence of scattered CNS deficit when examined.
2. "Disseminated progressive" Some patients insist that the course has been steadily progressive without a single remission.
3. "Recurrent optic neuritis" Visual loss due to unilateral optic neuritis. Most patients with optic neuritis do not show disseminated signs.
4. "Spinal-optic" Patients may present with concomitant involvement of both optic nerves and spinal cord. Often cerebellar and encephalitic signs are present as well.

(1) Leibowitz and Alter. p. 254.

(2) Houston, Marrite A Textbook of Neurology 4th ed., Philadelphia; Lea and Fabiger 1967, p. 705.

(3) Exacerbation--a period when the disease is active.

5. "Spinal-recurrent" Some patients have several attacks each of which involves only the spinal cord. On examination, only signs suggesting spinal cord deficits are elicited.

6. "Spinal-progressive" Some patients have a slowly but relentlessly progressive course without evidence by history or examination of disseminated disease.

7. "Spinocerebellar" A progressive type with cerebellar ataxia. The most prominent symptom is often high gamma globulin levels in the spinal fluid."⁽⁴⁾

8. "Acute fulminating" There is massive involvement in one episode leading to early marked disability or death.

9. "Stationary" After the initial onset there is a residual deficit but no further exacerbations. There is partial remission with the patients condition becoming static."⁽⁵⁾

"The lesions in the myelin are generally in three specific areas of the CNS: 1) spinal cord; 2) brainstem; and 3) cerebrum."⁽⁶⁾ "The neurological deficits, the remissions, and the exacerbations of MS are attributable to these lesions."⁽⁷⁾

"The signs, symptoms and complaints of MS include: transient blindness, double vision; diplopia; vertigo; ataxia; nystagmus; scotoma; pallor of optic discs; numbness or weakness of one or more limbs; general weakness; sphincter disturbances;"⁽⁸⁾ loss of kinesthetic awareness and paralysis. "Despite this variability of symptoms according to Harrison 'most cases after a greater or lesser period of time

(4) Leibowity and Alter pp. 8-11.

(5) Licht, Sidney. op. 783 and 784

(6) Davis p. 6

(7) Leibowitz p. 2

(8) Ibid p. 3

follow a final common path of increasing spasticity, immobility and respiratory or urinary infection and death."⁽⁹⁾

There are various theories as to the cause of MS. 1) MS may be a delayed reaction to a viral childhood disease such as measles or polio. 2) MS may be caused by a virus which is latent within the individual until activated by trauma of infection. There seems to be support of a viral cause as people who are frequently exposed to MS as children tend to show immunity. 3) MS may be an autoimmunological disorder whereby the body fails to recognize its own tissue and attacks the myelin as if it were a foreign body. The viral and autoimmunological theories are believed to be closely related. 4) There may be an agent in the drinking water in areas where sanitation is poor. The theory is that the agent is taken into the body before myelinization is well established causing protective antibodies to develop. If the agent is taken in after myelinization, demyelinating antibodies develop. "If these speculations are valid, then, the agent which causes MS may be most common in the drinking water of environments where MS is rare."⁽¹⁰⁾ MS would be more prevalent in areas of better sanitation.

A high frequency of MS has been related to the following: 1) The incidence of MS tends to increase as the hours of annual sunlight decrease. 2) People whose diets are high in animal fat and gluten show a higher incidence of MS.^(11,12) 3) Areas which have one or more heavy metals in the soil show a higher incidence of MS. 4) People raised in temperate climates are more frequently afflicted with MS.

⁽⁹⁾ Davis pp. 6 and 7.

⁽¹⁰⁾ Leibowitz p. 351.

⁽¹¹⁾ Ibid--studies have shown positive correlation and no correlation

⁽¹²⁾ Subject no. 3 is on a low fat and gluten diet and claims that his body functions are much improved from the prediet condition.

The disease is not believed to be genetic, but there may be a genetic predisposition when one or more members of a family have the disease.

Therapeutic Exercise

Much of the disability in MS patients results from disuse of the muscles and from confinement to the wheelchair. Exercise is important to help maintain existing function and wherever possible to regain function which has been lost due to muscular atrophy or to joint stiffness.

"Muscle re-education is the traditional term used to designate that phase of the therapeutic exercise devoted to the development or recovery of voluntary control of skeletal musculature. It has two objectives 1) to develop motor awareness and voluntary response and 2) to develop strength and endurance in patterns of movement that are necessary, effective, safe, and acceptable."⁽¹³⁾

The buoyant force of water provides support which can allow the patient to move seriously weakened parts. As the weakened part develops, the water can provide a resistance which will aid in further strengthening of the muscles.

Shoulder Motion

"Movement of the shoulder requires action of the following muscles: supraspinatus; trapezius; deltoid; infraspinatus; biceps; coracobrachialis; teres major and minor; pectoralis major and minor; rhomboids; subscapularis; serratus anterior; and latissimus dorsi."⁽¹⁴⁾ Although the deltoid is a prime mover in abduction and elevation, these movements are still possible with paralysis of the deltoid.⁽¹⁵⁾

⁽¹³⁾ Licht, Sidney p. 472.

⁽¹⁴⁾ Ibid p. 93.

⁽¹⁵⁾ This can be noted in subject no. 3 as another study had indicated paralysis of the middle head of the deltoid.

Overarm Throw

"This throw is characterized by rotation at the shoulder joint. There is elbow and wrist extension and spinal rotation during the force phase."^(16,17) The flexion of the shoulder makes the greatest contribution to the velocity of the pitch."⁽¹⁸⁾

Changes in Movement in MS Patients Due to Exercise

The author was unable to locate any studies relating to this topic.

⁽¹⁶⁾ Wells, Katharine p. 464.

⁽¹⁷⁾ Other movements which involve the lower body are not applicable to this study.

⁽¹⁸⁾ Zollinger, Randa L. p. 290

CHAPTER IV

INTERPRETATION OF DATA

Interpretation of the individual throws was done by observation of the film, by analysis of the Recordak tracings, and by analysis of the data acquired using the Graphic Tablet and computer printout.

Subject I

Throw 1

Average force during power phase	2.1409 pounds	
In flight horizontal ball velocity	16.0000 ft/s	
Range of Motion (in inches) ⁽¹⁾	Horizontal	Vertical
Shoulder	6.6000	4.4000
Elbow	11.6000	10.4000
Wrist	25.0000	21.0000

The action of the throw appeared smooth; moving through the recovery, power, and follow through phases without pauses, backtracking motions, or spastic movements. During the recovery, shoulder flexion brought the hand high above the head with the shoulder almost fully abducted and the elbow almost fully extended. During recovery, there was a small amount of extension of the trunk with a return to the subject's normal position during the power phase. The elbow led in the power phase and did not start to extend until it was well forward.

(1) Displacements listed at the beginning of each throw's description include the follow through.

The wrist was hyperextended at the beginning of the power phase, extended at release, and flexed in the follow through. The impetus imparted to the ball appeared to be completely horizontal. During the follow through, the arm crossed the body. At no point during the throw was trunk rotation evident.

In this throw the movement of the ball⁽²⁾ was first forward 3.90 inches^(3,4) and upward 14.60 inches. The ball was then moved backward but continued to be carried upward to a point 27.20 inches above the starting position which was well above the subject's head and 13.50 inches behind the starting position. The recovery continued backward and downward reaching a maximum negative horizontal displacement of 23.5 inches and dropping to a vertical of 21.60 inches above the starting position (5.6 inches below the maximum height attained during recovery). The ball was then carried forward 25.9 inches and upward 9.10 inches and released (displacement from starting position--horizontal +2.4 inches--vertical +30.7 inches). The force imparted to the ball was almost totally in the horizontal direction. It was necessary to refer to the tracings and the data computed from those tracing to determine the upward flight of the ball which was .68 inches due to an average vertical force of .73 pounds.

Velocity decreased to 1.86 ft/s. during the recovery phase. During the power phase there was rapid acceleration followed by a more gradual acceleration to a release velocity of 15.04 ft/s.

(2) It should be noted that all displacements, velocities, and accelerations of the elbow, wrist, and ball will be affected by those points which are more proximal. All of these and the shoulder will be affected by movements of the trunk.

(3) All distances are approximations containing errors due to recording points from the film and due to rounding errors in computations which were done on a Hewlett-Packard 25 Calculator.

The average force applied to the ball during the power phase, which was approximately .14 seconds,⁽⁵⁾ was 2.14 pounds.

The action of the shoulder joint was irregular showing no pattern in horizontal displacement, in vertical displacement, or in the relationship of vertical and horizontal displacements. Pre-release ROM was -5.60 inches to +1.00 inches horizontally and -3.10 inches to 1.20 inches vertically.

The velocity of the joint was irregular due to short alternating periods of acceleration and deceleration. The maximum velocity attained was 9.50ft/s. Maximum acceleration was 215.14 ft/s² and maximum deceleration was 225.89 ft/s².

After an initial backward displacement of .70 inches and an upward displacement of .70 inches, the elbow showed no horizontal displacement for .20 seconds during which time it was raised another 3.90 inches. The action of the elbow was then backward and upward to a position 8.10 inches behind and 8.90 inches above the position. While the ball continued backward and downward for another .08 seconds, the elbow started to move forward. As the elbow started to move forward, there was an initial 1.40 inch drop then the upward action resumed. At release the elbow was .40 inches behind and 10.4 inches above its starting position. The path of the elbow during the follow through was forward and down. Pre-release ROM was -8.10 inches to 0.00 inches horizontally and 0.00 to +10.40 inches vertically.

As with the shoulder, the elbow was constantly alternating between acceleration and deceleration. The maximum velocity, acceleration, and deceleration were 10.00 ft/s, 120.56 ft/s², and 202.04 ft/s² respectively.

(4) Actual position in inches is not the same among throws.

(5) This was measured on the Recordas as the period from point of

The wrist and the ball follow almost identical paths with some variation due to hyperextension of the wrist during recovery and extension of the wrist during the power phase.⁽⁶⁾ The wrist moved forward 4.00 inches and upward 6.50 inches then moved backward but continued upward to a point 18.80 inches above the starting position. When the wrist was 18.80 inches above the starting position, it had moved backward 9.80 inches. The wrist now moved downward while continuing backward. The wrist dropped 3.30 inches before again moving upward. The wrists maximum backward displacement was 16.30 inches. The wrist moved upward 5.60 inches during the power phase (21.0 inches above the starting position). At release the wrist was .40 inches in front of its starting position and 19.70 inches above it. Pre-release ROM was -16.30 inches to 4.00 inches horizontally and 0.00 inches to 21.00 inches vertically.

The wrist decelerated at the end of the recovery phase from a velocity of 6.01 ft/s to a velocity of 1.27 ft/s. As with the other joints, acceleration and deceleration alternated throughout the movement. Maximum velocity, acceleration, and deceleration were 11.98 ft/s⁽⁷⁾, 154.15 ft/s², and 75.05 ft/s² respectively.

Throw 2

Average force during power phase	1.8651 pounds	
In flight horizontal ball velocity	17.2500 ft/s	
Range of Motion (in inches)	Horizontal	Vertical
Shoulder	3.7000	2.3000
Elbow	13.0000	8.2000
Wrist	25.4000	20.1000

greatest backward displacement of the ball to release. The actual power phase may have been longer depending on the skill of the throw.

The action of the throw appeared smooth. During the recovery phase the elbow remained well flexed and the shoulder abducted to approximately ninety degrees. There was a slight pause at the transition from the recovery phase to the power phase. After the pause, there was an inward rotation of the shoulder. During the power phase, the elbow led and the wrist was hyperextended. At release the elbow remained slightly flexed and the wrist was in a neutral position. The impetus imparted to the ball had a small upward direction but was mainly horizontal. In the follow through, the shoulder and elbow extended, the wrist flexed, and the arm crossed the body.

The neck hyperextended at the beginning of the recovery phase and returned to neutral then hyperextended again at the beginning of the power phase returning to normal by the time of release. There was a slight rotation of the trunk during the follow through.

In this throw the movement of the ball was first forward .90 inches and upward 3.80 inches. The ball was then moved backward but continued to be carried upward to a point 24.30 inches above the starting position. At that point the ball had reached its greatest backward displacement which was 23.20 inches behind the starting position. The ball was then moved forward and after an initial drop of .08 inches, it continued to be carried upward. At release the ball was 4.70 inches in front of and 30.70 inches above its starting position. The Recordak tracings indicated that the power phase's average vertical force of .86 pounds gave the ball a rise of 2.87 inches.

(6) This was to be expected due to the proximity of the ball and the wrist.

(7) In this throw, the wrist was at its maximum velocity at the point of release.

During the recovery period, velocity was irregular due to short, alternating periods of acceleration and deceleration. At the beginning of the power phase, the ball was at its minimum velocity of 1.21 ft/s. Through the power phase, the ball was accelerated to a release velocity of 18.06 ft/s.

The average force applied to the ball during the power phase, which was approximately .18 seconds, was 1.87 pounds.

The action of the shoulder was irregular showing no pattern in horizontal displacement or in vertical displacement. There was, however, an apparent relationship between the horizontal and vertical displacements. Backward and upward motions occurred together. When the joint moved forward it usually moved downward, however; occasionally the joint moved forward and up. There was only one point, early in the recovery phase, in which the shoulder moved back and down. Pre-release ROM was -2.20 inches to 1.5 inches horizontally and -1.10 inches to 1.20 inches vertically.

The velocity of the joint was irregular due to short alternating periods of acceleration and deceleration. The maximum velocity attained was 5.15 ft/s. Maximum acceleration was 115.48 ft/s^2 and maximum deceleration was 105.07 ft/s^2 .

After an initial forward displacement of 1.30 inches and a downward displacement of 1.00 inch, the elbow moved backward and up. During recovery the horizontal displacement was basically backward with an occasional forward displacement. The elbow reached a maximum backward displacement of 3.40 inches and started forward .12 seconds before the ball started forward. During recovery the elbow was raised to a maximum of 3.90 inches, dropped .90 inches, and brought back up .50 inches. When the elbow was at the point of maximum backward hori-

zontal displacement, it was 3.50 inches above its starting position. During the power phase, the movement of the elbow was forward and basically upward. When the elbow was 2.50 inches behind the starting position, it dropped 1.20 inches then resumed an upward path. At release the elbow was 5.70 inches in front of and 7.40 inches above its starting position. The elbow continued upward for .04 seconds to a maximum height of 7.50 inches then dropped 2.50 inches in .12 seconds. The elbow continued to move forward throughout the period of analysis. Pre-release ROM was -3.40 inches to 5.70 inches horizontally and -1.00 to 7.40 inches vertically.

As with the shoulder, the elbow was constantly alternating between acceleration and deceleration. The elbow's minimum velocity, .42 ft/s, occurred early in the recovery phase. Its second slowest velocity, .63 ft/s, occurred at the transition between the recovery and power phases. The elbow attained its greatest velocity, 5.84 ft/s, .04 seconds before release. Maximum acceleration and deceleration were 116.94 ft/s^2 and 91.55 ft/s^2 respectively.

The wrist and the Ball followed almost identical paths with some variation due to hyperextension of the wrist during recovery and extension of the wrist during the power phase.⁽⁸⁾ The wrist moved to a point 18.70 inches behind and 17.10 inches above its starting position. The wrist started to move forward but continued upward .60 inches in .04 seconds. The wrist then dropped 1.50 inches in .04 seconds before resuming its upward path. The wrist reached a maximum upward displacement of 20.10 inches .08 seconds before release. At release the wrist was .20 inches in front of and 17.90 inches above its starting position. During the follow through, the wrist continued to move forward and down. Pre-release ROM was -18.70 inches to .20 inches horizontally and 0.00 inches to 17.90 inches vertically.

The wrist was at its slowest, .88 ft/s, at the beginning of the analysis. The wrist then accelerated and decelerated throughout the recovery phase with a maximum acceleration of 95.99 ft/s^2 and a maximum deceleration of 109.22 ft/s^2 . The velocity of the wrist was .93 ft/s⁽⁹⁾ .04 seconds after it started to move forward in the power phase. The wrist accelerated for .20 seconds to a velocity of 9.17 ft/s .04 seconds before release. At release the velocity of the wrist was 8.97 ft/s. The wrist attained its maximum velocity, 11.04 ft/s, .04 seconds after release.

Throw 3

Average force during power phase	1.8232 pounds	
In flight horizontal ball velocity	19.6619 ft/s	
Range of Motion (in inches)	Horizontal	Vertical
Shoulder	3.6144	6.3253
Elbow	9.4377	12.4499
Wrist	19.0762	16.3654

The throw was smooth except for a pause at the beginning of the power phase. The first movements of the arm during recovery were shoulder extension and elbow flexion. The shoulder was then flexed and abducted. The elbow remained flexed and was almost vertically beneath the wrist at the end of the recovery. In this throw the ball did not come behind the head. The wrist was hyperextended at the beginning of the power phase. The elbow led, however; early power phase action was predominately vertical with the hand beneath the ball. The majority of the action in the power phase was elbow extension. At release the elbow was slightly flexed and the hand was behind the ball with the wrist

(8) op cit

(9) This is the second slowest velocity recorded.

extended. In the follow through the shoulder and the elbow extended, the wrist flexed, and the arm crossed the body.

During recovery the head turned toward the left and returned to normal. During the power phase there was a slight extension of the trunk which returned to normal during the follow through. During follow through the head again turned left, but there was no trunk rotation.

In this throw the ball moved backward .20 inches then forward 2.41 inches. The ball moved back and forth within a 1.81 inch range for .12 seconds. For the next .04 seconds the ball moved backward to a point 18.57 inches behind its starting position. In the first .552 seconds the ball rose to a point 18.47 inches above the starting position. The ball dropped 4.82 inches and came back up 4.32 inches (17.97 inches above the starting position). At that time the ball started forward dropping 3.31 inches before resuming an upward path. At release the ball was 3.61 inches in front of and 28.41 inches above the starting position. The Recordak tracings indicated that the power phase's average vertical force of .94 pounds gave the ball a rise of 4.78 inches during flight.

The ball's minimum velocity, .47 ft/s, occurred .12 seconds after the beginning of the analysis. The ball's greatest recovery phase velocity was 13.95 ft/s .12 seconds before the ball began to move forward. The ball had a velocity of 1.80 ft/s .04 seconds after starting forward. The ball accelerated through most of the power phase to a velocity of 19.85 ft/s.

The average force applied to the ball during the power phase, which was approximately .20 seconds, was 1.82 pounds.

The action of the shoulder was irregular showing no consistent horizontal or vertical direction except for the period from .08 seconds before release to .12 seconds after release when the shoulder moved forward 2.70 inches. Usually, but not always, downward motion was coupled with forward motion. Backward and upward motion were generally coupled. Pre-release ROM was -1.80 inches to 1.80 inches horizontally and -4.62 inches to 1.51 inches vertically.

The velocity of the joint was irregular due to constant acceleration and deceleration with the longest period of each being .16 seconds. During the longest acceleration period the joint's velocity increased from .52 ft/s to 9.90 ft/s and during the longest deceleration period the joint's velocity decreased from 14.69 ft/s to .89 ft/s. Maximum velocity attained was 14.69 ft/s. The maximum acceleration and deceleration were 202.41 ft/s^2 and 218.53 ft/s^2 respectively.

During the first .20 seconds, the elbow moved backward and returned to the starting position twice. It then moved steadily backward to a point 5.42 inches behind the starting position. It then moved forward 3.71 inches and back 2.61 inches. The elbow and the ball began forward motion at the same time. At one point during the power phase the elbow moved sharply backward 1.51 inches and forward 1.52 inches. At release the elbow was 1.00 inch in front of its starting position. The elbow moved forward during the follow through. The elbow's initial vertical displacement was .50 inches upward. It then moved up and down, reaching a maximum downward displacement of 3.11 inches and a maximum upward displacement of 4.82 inches, until .20 seconds before release when it followed an upward path until .04 seconds after release. Follow through of the elbow was downward. The upward movement of the elbow, during the power phase, began .04 seconds after forward motion began. Pre-release

ROM was -5.42 inches to 1.04 inches horizontally and -3.11 inches to 9.04 inches vertically.

Elbow velocity varied greatly from a low of .46 ft/s early in the recovery phase to a high of 13.87 ft/s at the point where the elbow moved forward after maximum backward displacement. The second highest velocity was 10.98 ft/s as the elbow immediately moved backward before beginning its final forward path. The elbow decelerated immediately before release. Maximum acceleration and deceleration were 189.94 ft/s^2 and 144.49 ft/s^2 respectively.

The wrist and the ball follow almost identical paths ⁽¹⁰⁾ with some variation due to wrist action. The wrist first moved forward and down 3.51 inches and 1.00 inches respectively. It then moved back and up to a point 12.35 inches behind and 11.35 inches above the starting position. After .20 seconds, during which motion fluctuated in both planes, the wrist moved forward and up to a release point .60 inches behind and 15.36 inches above the starting position. The follow through was forward and down. Pre-release ROM was -12.35 inches to 3.51 inches horizontally and -1.00 inches to 15.56 inches vertically.

As the ball started forward, the wrist paused, therefore; the minimum velocity of the wrist was 0.00 ft/s. During recovery the wrist was usually accelerating. After an initial deceleration, at the beginning of the analysis, the wrist accelerated for .28 seconds from a velocity of 1.48 ft/s to a velocity of 7.42 ft/s. In the next .04 seconds there was a deceleration of 174.00 ft/s^2 to a velocity of .47 ft/s. The wrist then accelerated for .16 seconds to a velocity of 119.42 ft/s. The wrist decelerated at an increasing rate as it reached its maximum backward displacement. At release, wrist velocity was 6.08 ft/s. Immedi-

(10). op cit footnote 6

ately after release wrist velocity was at its maximum of 13.13 ft/s then the wrist decelerated at a decreasing rate. Maximum acceleration and deceleration were 176.24 ft/s^2 and 255.38 ft/s^2 respectively.

Throw 4

Average force during power phase	2.6408 pounds	
In flight horizontal ball velocity	17.6749 ft/s	
Range of Motion (in inches)	Horizontal	Vertical
Shoulder	4.3177	11.2449
Elbow	10.8433	11.6467
Wrist	23.7953	22.8914

The throw was smooth except for a pause at the beginning of the power phase. The first movements of the arm were shoulder extension and elbow flexion. With the elbow remaining flexed, the shoulder flexed and abducted. During the recovery, the ball came above the subject's head and was carried well behind the subject.⁽¹¹⁾ The wrist was hyperextended at the beginning of the power phase. The elbow led in the power phase. At release the ball was above and in front of the subject, the shoulder was flexed to about 130 degrees, the elbow was almost fully extended, and the wrist was extended. Immediately after release, the elbow extended and the wrist flexed. During the follow through the arm crossed the body.

The head turned to the left during recovery coming back to normal. The trunk extended slightly during the power phase returning to the normal. Although the head definitely turned toward the left during the follow through, the trunk did not rotate.

Range of motion and mechanics appeared to be the best in this throw compared to the subject's other three throws.

(11) This throw appeared to have greater shoulder flexion than the other three throws.

In this throw the movement of the ball was first forward .40 inches and upward 1.51 inches. For the next .12 seconds the ball moved backward and upward to a point 14.86 inches behind and 26.10 inches above the starting position. During the next .08 seconds the ball traveled backward another 8.13 inches, dropped 3.41 inches and returned to its vertical position. The ball continued to move backward for .12 seconds to its maximum backward displacement of 38.11 inches. From its maximum vertical recovery point of 26.10 inches above the starting point the ball dropped 11.74 inches in .24 seconds. By this time the ball had moved forward 4.72 inches to a point 23.39 inches behind the starting position. The ball now moved forward and up to the release point which was .90 inches in front of and 35.84 inches above the starting position. The Recordak tracings indicated that the power phase's average vertical force of 1.23 pounds gave the ball a rise of 5.35 inches. This was the greatest vertical rise among the four throws.

Early in the recovery, velocity was irregular due to short, alternating periods of acceleration and deceleration. Surrounding the point of transition from the recovery phase to the power phase, there was a long (.20 seconds) period of deceleration which decreased velocity from 11.30 ft/s to 1.34 ft/s. The ball was then accelerated and decelerated rapidly through the point of release. Release velocity was 21.82 ft/s.

The average force applied to the ball during the power phase, which was approximately .12 seconds, was 2.64 pounds.

The action of the shoulder was irregular showing no pattern in horizontal displacement, vertical displacement, or in the relationship of horizontal and vertical displacements until the ball was released. Following the release of the ball, the shoulder moved forward and up

.16 seconds. Pre-release ROM was -3.01 inches to 1.31 inches horizontally and -8.53 inches to 2.71 inches vertically.

The velocity of the joint was irregular due to short, alternating periods of acceleration and deceleration. The maximum velocity, acceleration and deceleration were 16.36 ft/s, 354.99 ft/s², and 344.41 ft/s² respectively.

After an initial 5.62 inches backward and a 3.31 inches upward displacement, the elbow moved forward 1.00 inch while continuing upward 1.91 inches. The wrist then resumed a backward and upward path. Maximum upward, recovery displacement was 10.84 inches. During the power phase, the elbow moved consistently forward; vertical motion, however, was erratic. After a high point of 10.84 inches, the elbow dropped 8.73 inches, rose 9.53 inches, dropped 2.91 inches and rose 3.72 inches to its maximum vertical displacement of 11.65 inches. Maximum vertical displacement occurred at the point of release. Pre-release ROM was -8.33 inches to -0.30 inches horizontally and 0.00 inches to 11.65 inches vertically.

As with the shoulder, the elbow was constantly alternating between acceleration and deceleration. The elbow's minimum velocity, .42 ft/s, occurred early in the recovery phase and .12 seconds after release. The second slowest velocity, .86 ft/s, occurred at the transition between the recovery and power phases. The elbow's greatest velocity, 19.69 ft/s, occurred .16 seconds before release. At release the elbow had decelerated to 7.97 ft/s. Maximum acceleration and deceleration were 445.00 ft/s² and 428.61 ft/s² respectively.

The wrist and the ball follow almost identical paths⁽¹²⁾ with some variation due to wrist action. In the first .04 seconds, the wrist

(12) op cit footnote 6

moved forward 2.61 inches. It then moved backward to a point 20.38 inches behind its starting position. The wrist moved upward 2.01 inches in the first .04 seconds, dropped .20 inches in the next .04 seconds, then moved upward 16.66 inches in the next .28 seconds (18.47 inches above the starting position), dropped 3.21 inches, rose 4.22 inches, and then fluctuated within a 2.00 inch range. When the wrist reached its maximum backward displacement, it was 17.57 inches above the starting position. The wrist moved forward throughout the remainder of the analysis. As the wrist started forward, it dropped 7.53 inches in .12 seconds, rose 12.85 inches in .08 seconds, fluctuated vertically for another .08 seconds, then moved downward through the remainder of the analysis. At release the wrist was .90 inches behind and 21.59 inches above the starting position. The follow through was forward and down. Pre-release ROM was -20.38 inches to 2.61 inches horizontally and 0.00 inches to 21.59 inches vertically.

Eight-hundredths of a second after it started forward the wrist paused, therefore; minimum velocity of the joint was 0.00 ft/s. The wrist accelerated and decelerated throughout the recovery. The wrist accelerated for the majority of the power phase then began a final period of deceleration just prior to release. The maximum velocity of the wrist was 23.40 ft/s .12 seconds before release. At release, the velocity was 9.99 ft/s. Maximum acceleration and deceleration were 388.45 ft/s^2 and 372.12 ft/s^2 respectively.

Comparison by throw

	least		Greatest	
Average force during power phase	3 (.20 sec.)		4 (.12 sec)	
In flight horizontal ball	1		3	
Range of Motion	<u>Hor</u>	<u>Vert</u>	<u>Hor</u>	<u>Vert</u>
Shoulder	3	2	1	4

Elbow	3	2	2	3
Wrist	3	3	4	4
<u>Averages</u>	Pre		Post	
Force during power phase (in pounds)	2.00		2.23	
In flight horizontal ball velocity	16.63 ft/s		18.67 ft/s	
Displacements in inches				
Shoulder				
Horizontal	5.15		3.97	
Vertical	3.30		8.68	
Elbow				
Horizontal	8.61		7.23	
Vertical	9.40		11.98	
Wrist				
Horizontal	19.60		19.43	
Vertical	20.55		19.08	

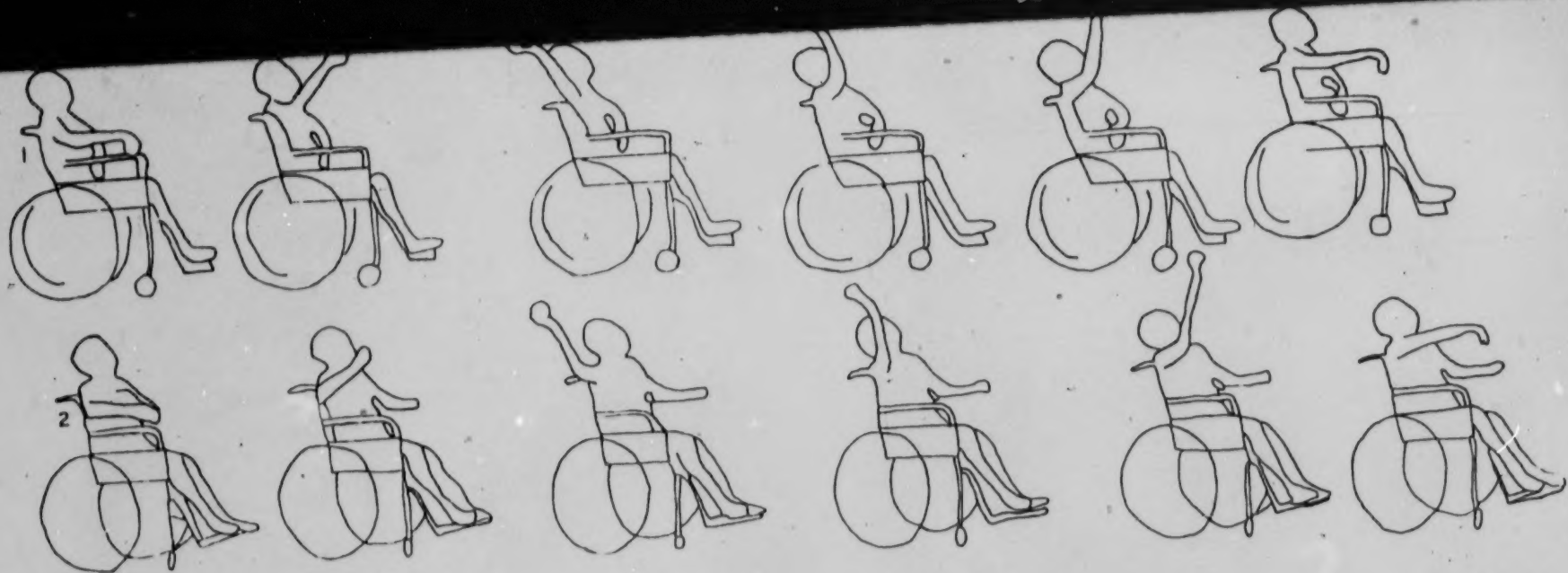
It is evident that the average force during the power phase did not correlate with the horizontal ball velocity. This was due to the variation in lengths among power phases. The average force of the power phase decreased as the length of the power phase increased. It is also evident that the throw with the greatest horizontal ball velocity was not the throw with the greatest range of motion. Horizontal ball velocity was greater in both throws three and four than in throws one and two.

With Subject 1, average vertical displacement of the shoulder and average vertical displacement of the elbow increased. All other average displacements decreased. In all throws the information on the shoulder will be the least accurate because of the difficulty in pinpointing the joint center. There were times when the tape indicating the landmark was difficult to see.

Figure 1 shows the starting position, a mid-point recovery position, the position, as nearly as could be determined visually, when the ball reached its maximum backward displacement, a position midway through the power phase, the point of release, and a position near the end of the follow through. As the data indicated, Figure 1.4 shows the greatest range of motion of the limb.

Graphs IA-ID show the displacements of the ball, shoulder, elbow, and wrist for throws two and three which were the pre and post throws with the greatest in flight horizontal ball velocity. The x indicates the starting point for each throw and the position at release is underlined. Graph IB shows a definite increase in vertical displacement. It also shows that the over all movement of the shoulder was more expansive in throw three than in throw two. Graph IC shows a large increase in vertical displacement of the elbow. This can be seen in Figures 1.2 and 1.3 by the low recovery position of the elbow in Figure 1.3. Throw three appeared to be more of a pushing action. Graph ID shows the decrease in wrist displacement, but note the more expansive motion at the transition between the recovery and power phases.

For this subject the post activity throws seemed more efficient as there was more force developed in less time. Although a decrease in ROM was indicated, the subject moved more effectively.



28

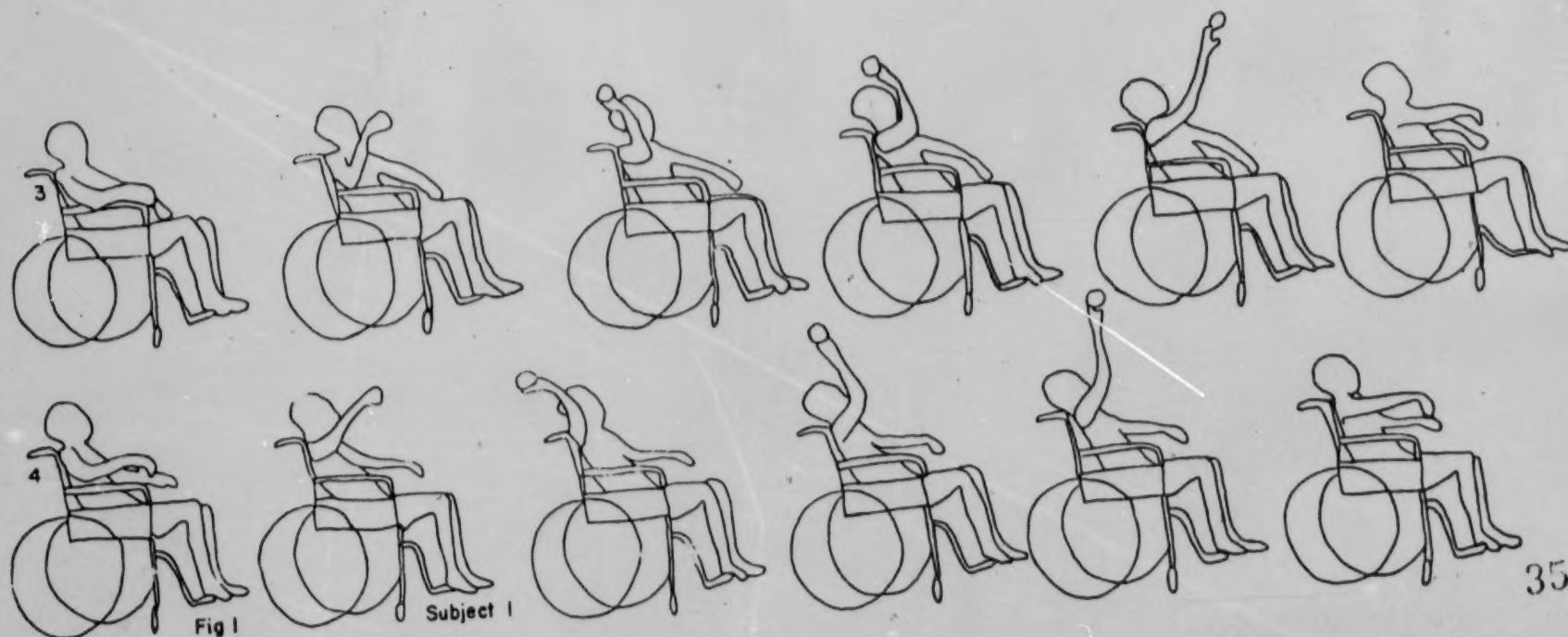


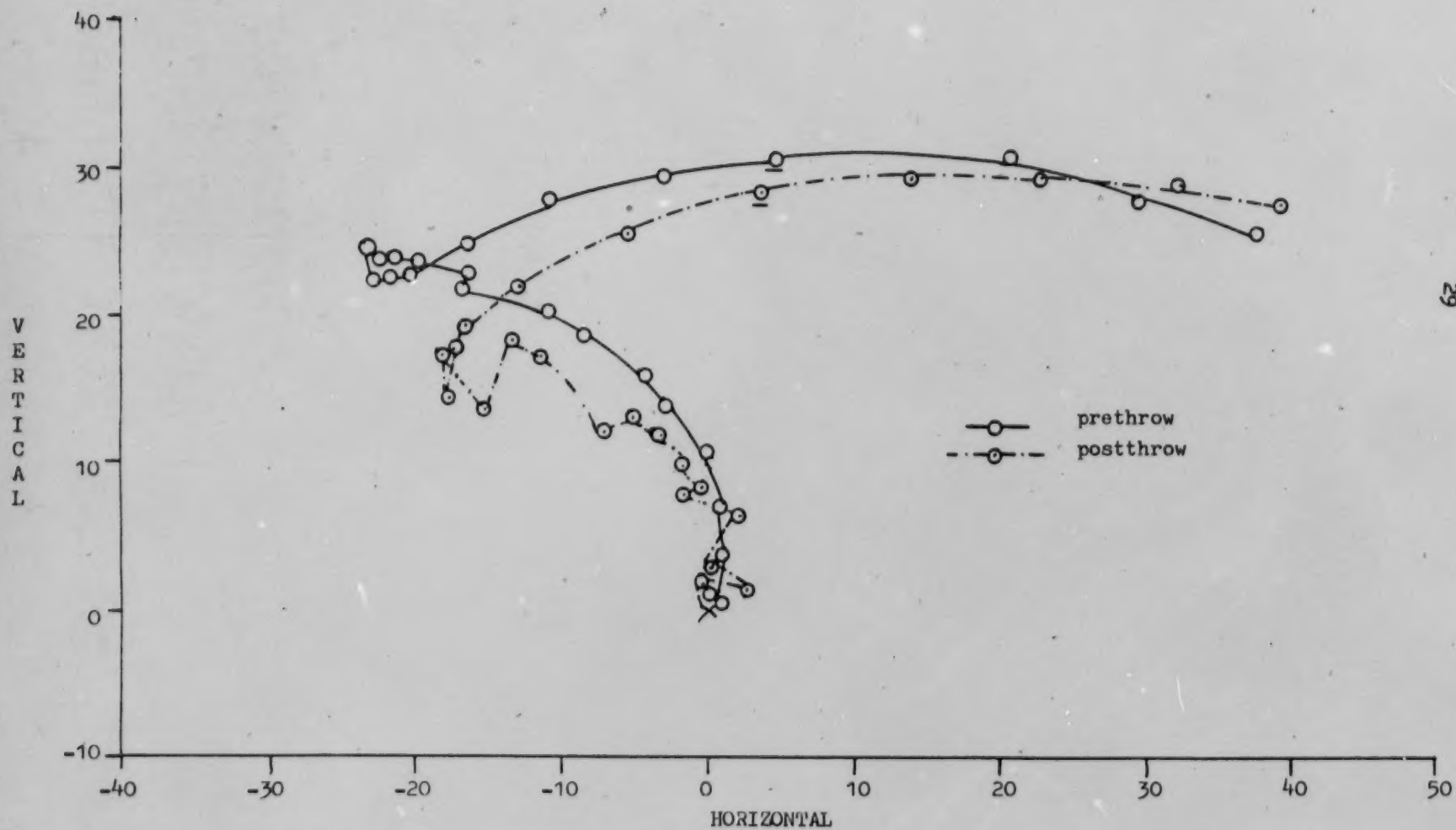
Fig 1

Subject 1

34

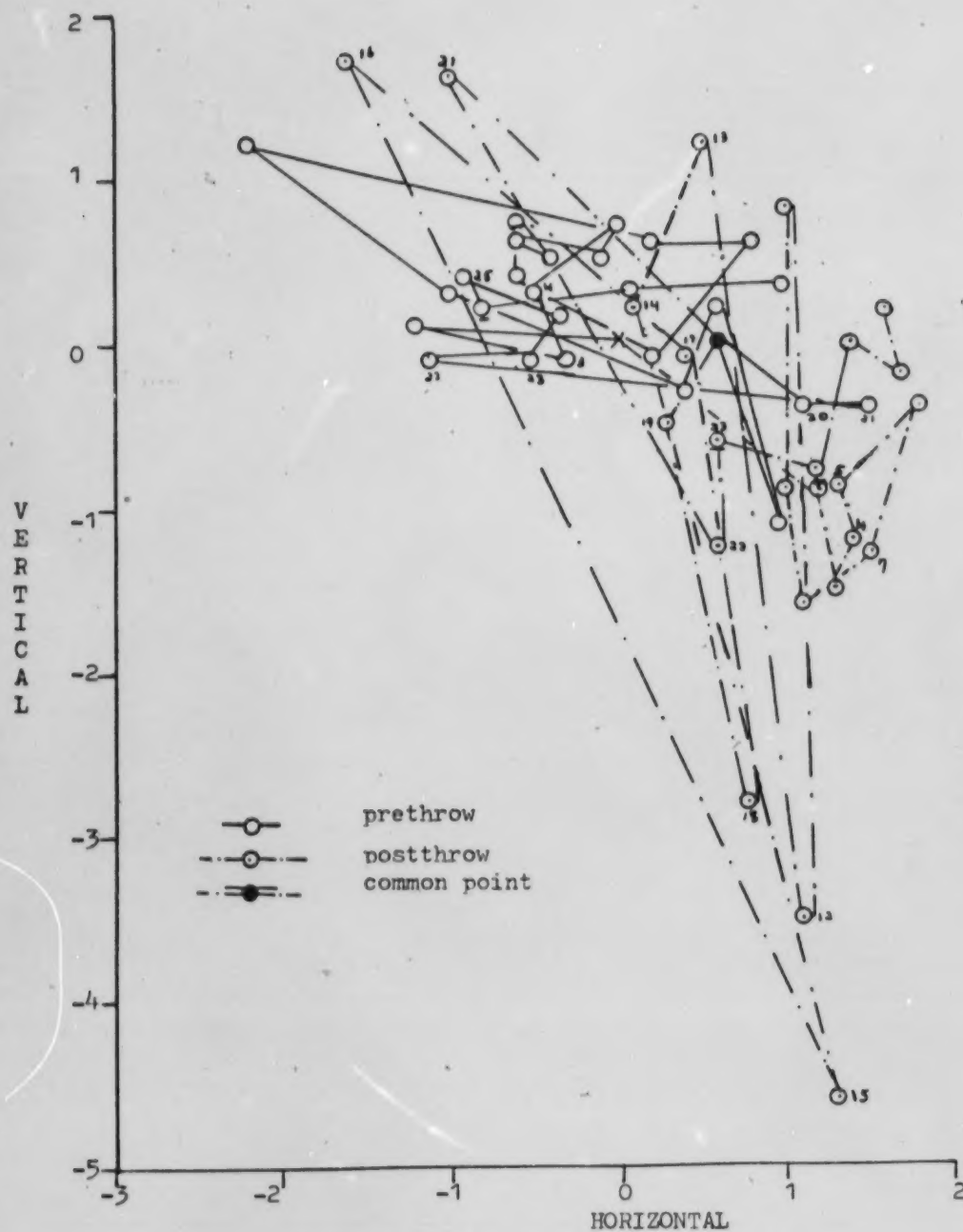
35

GRAPH 1A SUBJECT 1 THROWS 2 AND 3 BALL DISPLACEMENT IN INCHES

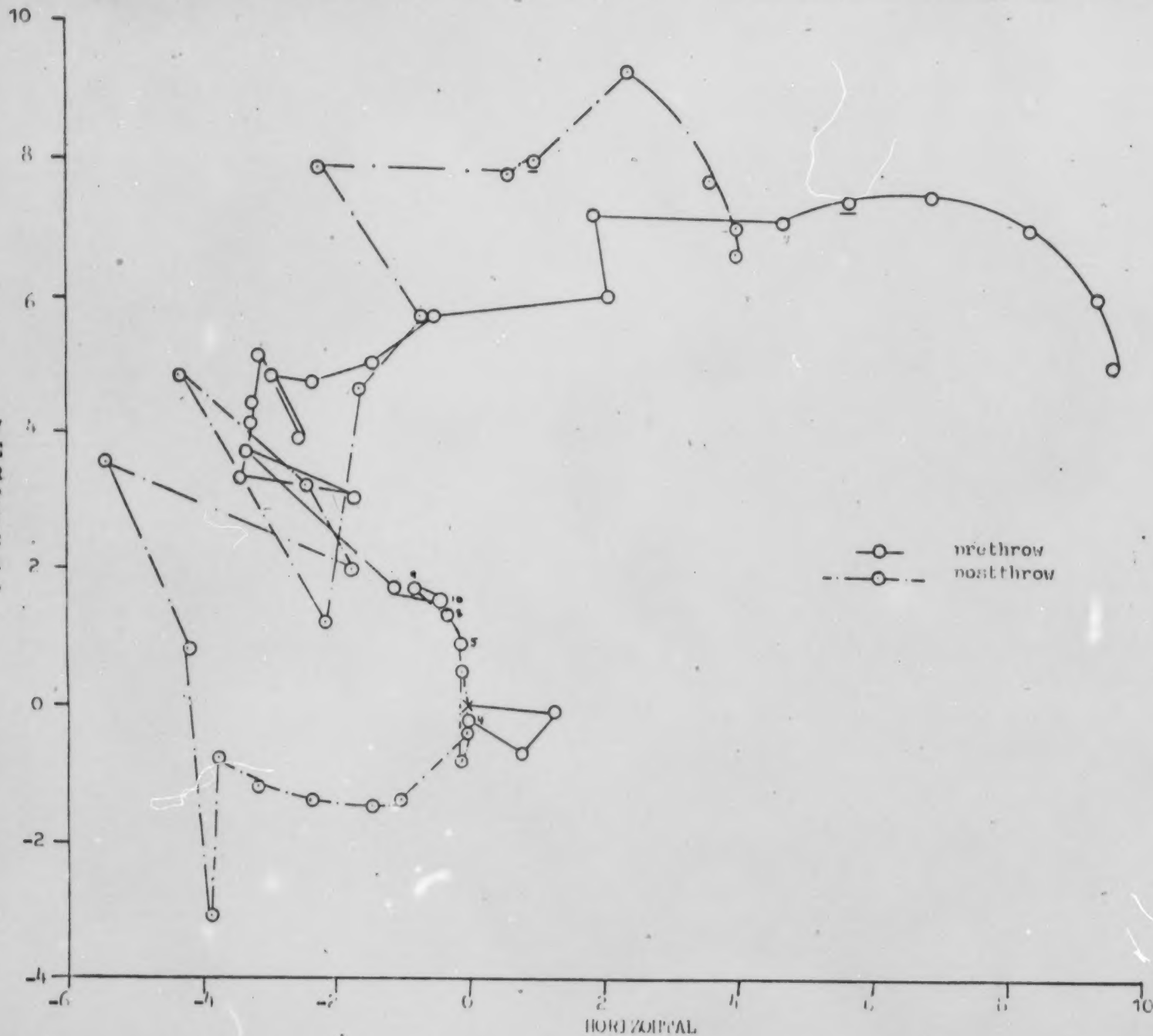


29

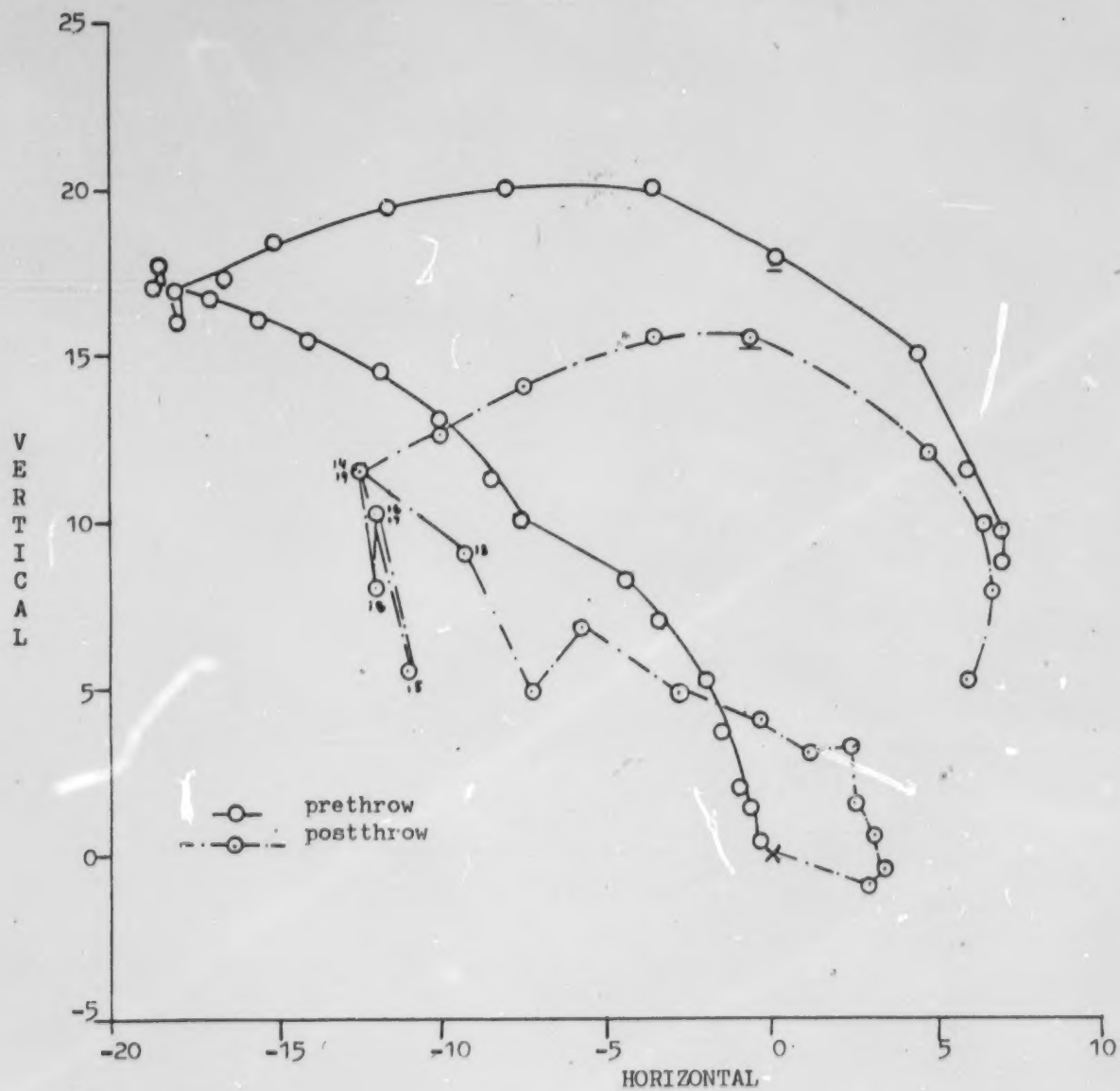
GRAPH 1B SUBJECT 1 THROWS 2 AND 3 SHOULDER DISPLACEMENT IN INCHES



VERTICAL



GRAPH ID SUBJECT 1 THROWS 2 AND 3 WRIST DISPLACEMENT IN INCHES



Subject II

Throw 1

Average force during power phase	0.6336 pounds	
In flight horizontal ball velocity	13.0865 ft/s	
Range of Motion (in inches)	Horizontal	Vertical
Shoulder	6.1554	7.2655
Elbow	16.4480	12.6843
Wrist	27.4468	15.9437

In this throw, which was basically a pushing action, there was a definite pause between the recovery and power phases giving the action a jerky effect. The preliminary backward lean of the torso appeared to be used to develop momentum for the arm action which followed. The initial action of the arm was flexion of the elbow and hyperextension of the shoulder. The shoulder then abducted and rotated outward bringing the ball to a position slightly above and behind the shoulder. The elbow remained low and flexed to less than ninety degrees. With the hand directly beneath the ball, horizontal flexion with a slight amount of shoulder flexion⁽¹³⁾ brought the ball forward and raised it to approximately eye level. Extension of the elbow pushed the ball forward and down to the point of release. At release the wrist was still hyperextended. The follow through involved extension of the shoulder and elbow and flexion of the wrist. There was no cross body action. During the follow through the trunk came forward very slightly. Action of the trunk is more of a body lean than flexion or extension as subject has very little trunk mobility.

In this throw the movement of the ball was first forward 3.43 inches and upward 5.95 inches. The ball was then moved backward, but

(13) The shoulder now has approximately ninety degrees of flexion.

continued to be carried upward to a point 16.15 inches behind and 16.65 inches above the starting position. The path of the ball was then backward and down until it reached a point 20.18 inches behind and 12.21 inches above the starting position. The ball moved backwards for another .04 seconds to a maximum backward displacement of 22.60 inches. Vertical action fluctuated within a 2.93 inch range for the next .24 seconds then followed an upward path until .12 seconds before release. At that time it was 23.51 inches above the starting position. The final action of the power phase was forward and down to a release point 11.71 inches above and 19.48 inches in front of the starting position. The force imparted to the ball was predominately vertical. The average horizontal force imparted to the ball during the power phase, which was approximately .56 seconds, was .37 pounds. Vertical force was directed downward and did not contribute to the effectiveness of the throw.

During recovery and during the majority of the power phase, velocity was erratic due to constant acceleration and deceleration. For the final .12 seconds of its backward motion the ball was accelerated from 2.32 ft/s to 7.29 ft/s. In the first .12 seconds of its forward path the velocity of the ball decelerated to 1.60 ft/s. During the power phase, the ball reached its maximum velocity of 13.71 ft/s then decelerated rapidly to 7.85 ft/s before accelerating along the downward path to release. At release ball velocity was 14.69 ft/s.

The average linear force applied to the ball during the power phase was .63 pounds.

From the beginning of the analysis until .16 seconds before the ball started forward, the horizontal action of the shoulder was predominately backward to a maximum recovery phase displacement of 2.93 inches. The shoulder then moved forward 1.21 inches in .12 seconds and back 1.01

inches as the ball started forward. Horizontal motion was then erratic until .20 seconds before the release of the ball when the shoulder started moving forward. It continued to move forward for .08 seconds following release. Forward displacement during that period was 2.62 inches. Vertical motion of the shoulder was erratic following no pattern. At the point of greatest horizontal displacement, -3.23 inches, the shoulder was 1.31 inches below the starting position. At release the shoulder was 1.61 inches behind and .30 inches below its starting position. Pre-release ROM was -6.16 inches to 0.00 inches horizontally and -5.55 inches to 1.72 inches vertically.

The velocity of the joint was irregular due to short alternating periods of acceleration and deceleration. Maximum velocity, acceleration, and deceleration were 12.57 ft/s, 280.72 ft/s², and 267.52 ft/s² respectively.

During the first .20 seconds of analysis the elbow moved backward 5.45 inches and upward 2.52 inches. The elbow continued backward for .28 seconds to a point 12.01 inches behind the starting position (vertical position: -1.21 inches). During this time vertical displacement fluctuated within a 3.23 inch range. In the next .12 seconds the elbow moved forward 4.64 inches and down 4.14 inches. For the next .28 seconds movement fluctuated in both planes. For .44 seconds prior to release and for .08 seconds after release, horizontal motion of the elbow was forward for a displacement of 16.45 inches. For .40 seconds before and .04 seconds after release, vertical displacement of the elbow was essentially upward for a displacement of 9.08 inches. At release the elbow was 1.61 inches ahead of and 7.27 inches above its starting position. Pre-release ROM was -13.22 inches to 1.61 inches horizontally and -4.24 inches to 7.27 inches vertically.

The joint was constantly accelerating and decelerating except for the .16 second period prior to the beginning of the ball's forward motion. During that time the elbow accelerated from a velocity of 1.60 ft/s to a velocity of 8.11 ft/s. As the ball started forward the elbow decelerated at a rate of 185.33 ft/s^2 to a velocity of 3.78 ft/s and continued to decelerate for .08 seconds to a velocity of 1.69 ft/s. The maximum velocity, acceleration and deceleration were 11.78 ft/s, 215.50 ft/s^2 , and 185.33 ft/s^2 respectively.

The wrist and the ball follow almost identical paths with some variation due to movements of the wrist.⁽¹⁴⁾ The wrist moved back and up for .08 seconds, forward and up for .04 seconds, and then backward and upward for .32 seconds to a point 10.49 inches behind and 9.08 inches above the starting position. The wrist continued backward for another .20 seconds to a maximum backward displacement of 19.48 inches. The joint then fluctuated horizontally within a 3.73 inch range for .24 seconds before beginning forward displacement in the power phase.

From .36 seconds after the start of the analysis until .84 seconds after the start the wrist fluctuated vertically within a 5.15 inch range. At the point of maximum backward displacement, the elbow was 9.79 inches above the starting position. The wrist then moved upward for .16 seconds, took a sharp drop of 3.73 inches in .08 seconds, then resumed an upward path for .08 seconds to the point of maximum vertical displacement (15.94 inches above the starting position) which occurred .16 seconds before release. The wrist moved downward for the remainder of the throw.

The position of the wrist at release was 6.76 inches in front of and 11.40 inches above the starting position. Pre-release ROM was

(14) op cit footnote 6

-19.48 inches to 6.75 inches horizontally and 0.00 inches to 15.94 inches vertically.

The joint's velocity was irregular due to continual alteration between acceleration and deceleration. The longest periods of acceleration or deceleration were .12 seconds. The maximum velocity, 12.49 ft/s, which occurred during recovery, exceeded the maximum power phase velocity by .04 ft/s. Maximum acceleration and deceleration were 211.15 ft/s^2 and 152.76 ft/s^2 respectively.

Throw 2

Average force during power phase	0.8483 pounds	
In flight horizontal ball velocity	12.1931 ft/s	
Range of Motion (in inches)	Horizontal	Vertical
Shoulder	4.7427	5.0454
Elbow	12.2100	9.0816
Wrist	22.0988	11.8063

This throw, which was not smooth in appearance, was a pushing action from the shoulder. While the elbow continued to flex and the wrist to hyperextend, the shoulder extended, abducted, and rotated downward bringing the ball to a position in line with the upper arm and just below the shoulder. At that point, the elbow was fully flexed and directly below the ball and the wrist was hyperextended. The ball was then moved forward and up with shoulder flexion, elbow extension and a slight backward action of the trunk. Before the elbow was full extended, the shoulder started to extend. At release the ball was directed forward and down.

In this throw the ball was initially moved forward 2.12 inches and upward 4.64 inches. Its displacement was then backward and up to a point 9.38 inches behind and 11.30 inches above the starting position.

In the next .12 seconds the ball continued backward to its greatest backward displacement (17.56 inches) while it dropped 2.32 inches and reascended 2.93 inches. The ball moved forward and back 2.22 inches in the next .12 seconds while ascending to a point 14.03 inches above the starting position. In the next .12 seconds the ball moved forward 2.42 inches and back 2.12 inches before beginning its final forward displacement. Vertical displacement fluctuated until .35 seconds before release when the ball began to ascend to its high point of 18.87 inches above the starting position. The high point was attained .24 seconds before release and maintained for .04 seconds. The ball descended before release. The exact position at the point of release was not obtained.⁽¹⁵⁾ The average horizontal force imparted to the ball was .67 pounds.

Velocity was irregular throughout the entire throw. There was continual alteration between acceleration and deceleration with neither continuing for longer than .12 seconds. The greatest pre-release velocity attained, 13.07 ft/s, occurred during recovery.⁽¹⁶⁾ Four-hundredths of a second prior to release ball velocity was 12.87 ft/s.

The average force applied to the ball during the power phase, which was .24 seconds, was .85 pounds.

Shoulder displacement was erratic in both the vertical and horizontal planes. There were times when motion did not occur in one or the other of the planes and at no time prior to release was there continuous motion in any direction for more than .12 seconds. From .04 seconds prior to release through the remainder of the analysis, hori-

(15) The position was measured, but the data point was obviously inaccurate. The point of release was assumed from the horizontal ball velocity computed from the surrounding points.

(16) The exact release velocity was indeterminate, but may have been greater.

zontal displacement of the shoulder was forward. At release the joint was .81 inches behind and 2.02 inches below the starting position. Pre-release RCM was -3.94 inches to .20 inches horizontally and -5.50 inches to 0.00 inches vertically.

Acceleration and deceleration of the shoulder alternated throughout the throw. The longest period of deceleration, .16 seconds, occurred early in the recovery phase slowing the joint from a velocity of 3.57 ft/s to a velocity of .21 ft/s. The longest period of acceleration, .12 seconds, occurred during recovery accelerating the joint from 2.66 ft/s to its greatest velocity of 6.94 ft/s. At one point during the throw, shoulder velocity was constant at 5.12 ft/s for .04 seconds. The joint then decelerated for .08 seconds to the point of release. Maximum acceleration and deceleration were 132.62 ft/s² and 116.88 ft/s² respectively.

Displacement of the elbow was essentially backward and down for the first .44 seconds. During this time there were two points where the elbow moved upward for .08 seconds and then resumed downward displacement. At the end of the .44 seconds, the elbow was 6.76 inches behind and 2.52 inches below the starting position. During the next .12 seconds, the elbow continued backward, however; its vertical motion brought the joint within .10 inches of the vertical starting position and returned the joint to a point 2.52 inches below the starting position. The elbow reached a downward displacement of 4.84 inches .16 seconds before starting forward from the maximum backward displacement of 7.97 inches. Fifty-two hundredths of a second before release the elbow started forward and continued to displace forward for the remainder of the analysis. At release the elbow was 2.62 inches in front of and 2.12 inches above the starting position. Pre-release RCM was -7.97 inches to 2.62 inches horizontally and -6.16 inches to 2.93 inches vertically.

Acceleration and deceleration alternated throughout the analysis with the longest period of each being .16 seconds. During the .16 second period of acceleration, which began .16 seconds into the recovery phase, the velocity of the joint increased from .47 ft/s to 3.97 ft/s. The .16 second period of deceleration occurred in the power phase. During this time the joint slowed from its maximum velocity of 10.31 ft/s to a velocity of 1.52 ft/s. At release the velocity of the elbow was 2.07 ft/s. Maximum acceleration and deceleration were 137.90 ft/s^2 and 122.14 ft/s^2 respectively.

The wrist moved forward .20 inches and up 2.12 inches before beginning a backward and up motion which lasted for .56 seconds and brought the wrist to a point 16.85 inches behind and 9.38 inches above the starting position. During the next .08 seconds, the wrist moved forward 2.52 inches and back 1.11 inches; it then began a forward displacement which continued until the point of release when the wrist moved backward .20 inches. Immediately after release the wrist moved forward .61 inches. Displacement was then backward. From the vertical point of 9.38 inches, the wrist fluctuated within a 2.92 inch range for the next .20 seconds then climbed to its maximum horizontal displacement of 11.81 inches in .12 seconds. From the point of maximum vertical displacement, which was attained .24 seconds before release, vertical displacement was directed downward for the remainder of the analysis. At release the joint was 4.64 inches in front of and 2.83 inches above the starting position. Pre-release ROM was -16.85 inches to 4.84 inches horizontally and 0.00 to 11.81 inches vertically.

There were two .16 second periods of acceleration during this throw. The first, during which the joint accelerated from .87 ft/s to 2.77 ft/s, occurred early in the recovery phase. The second, during which the joint

accelerated from 2.54 ft/s to 8.35 ft/s, occurred in the power phase and ended .12 seconds before release. During the following .12 seconds, the wrist decelerated to 3.16 ft/s, accelerated to 9.03 ft/s, and decelerated to a release velocity of 2.27 ft/s. There were no periods of deceleration longer than .08 seconds. Maximum velocity, acceleration, and deceleration were 10.86 ft/s, 111.91 ft/s², and 213.47 ft/s² respectively.

Throw 3

Average force during power phase	1.9661 pounds	
In flight horizontal ball velocity	16.7599 ft/s	
Range of Motion (in inches)	Horizontal	Vertical
Shoulder	6.2959	5.2476
Elbow	25.2885	17.3138
Wrist	34.4177	29.1710

The throw was smooth with no pause between the recovery and power phases. Initial actions included a backward lean of the trunk, elbow flexion to less than ninety degrees but more than forty-five degrees, and slight abduction of the shoulder. The shoulder then extended horizontally, rotated downward, and abducted to approximately ninety degrees. The wrist hyperextended bringing the hand directly under the ball. The upper arm was now at approximately shoulder level; the elbow was diagonally backward and flexed to approximately ninety degrees; and the ball was behind the head at about ear level. In the power phase, the elbow led, the trunk rotated toward the left, the shoulder flexed horizontally, the elbow extended, and the wrist flexed. The ball was carried forward and up. At release the elbow and the wrist were extended and the shoulder was flexed to approximately 135 degrees. During the follow through, the

shoulder extended and adducted bringing the arm across the body, the elbow flexed, and the trunk came forward and continued to rotate.

During the first .28 seconds of the analysis, the path of the ball was forward and up to a point 4.72 inches in front of and 14.38 inches above the starting position. During the next .04 seconds, the ball was moved rapidly backward to a point .73 inches behind and 17.00 inches above the starting position. The path of the ball continued to be backward and up to a point 18.47 inches behind and 24.34 inches above the starting position. The maximum backward displacement of 25.39 inches was reached .12 seconds later. During the transition from the recovery phase to the power phase, ball displacement fluctuated in both planes. The path of the ball became forward and up .48 seconds before release. Horizontal displacement continued to be forward for the remainder of the analysis. Vertical displacement reached a maximum of 39.77 inches .04 seconds before release. At release the ball was 20.36 inches ahead of and 39.45 inches above the starting position.

During the first .20 seconds of analysis, the ball was accelerated from a velocity of 1.38 ft/s to a velocity of 7.73 ft/s. The ball was then decelerated for .08 seconds, accelerated for .04 seconds and decelerated for .04 seconds. For the next .16 seconds, the ball accelerated to a velocity of 10.50 ft/s. From that point until .32 seconds before release, periods of acceleration and deceleration never exceeded .08 seconds. During the period which lasted from .32 seconds before release to .04 seconds before release, the ball was accelerated from a velocity of 1.66 ft/s to a velocity of 24.02 ft/s. The ball was rapidly decelerated into the release velocity of 15.75 ft/s.

This throw was the subject's only throw in which an upward impetus was imparted to the ball at release. The average vertical force applied

to the ball in the power phase, which was approximately .22 seconds, was .76 pounds. This force gave the ball a rise of 2.18 inches. The average force imparted to the ball during the power phase was 1.97 pounds.

During the first .24 seconds, horizontal displacement of the shoulder was backward 1.99 inches. During that time vertical displacement was upward .22 inches, backward .42 inches and forward .20 inches. For the next .32 seconds there was no pattern of motion in either plane. During the next .16 seconds, the shoulder moved backwards 2.94 inches to its maximum backward displacement of 4.93 inches. The horizontal displacement did not change for .04 seconds. Meanwhile, for .12 seconds the shoulder moved downward to a point 3.51 inches below the starting position. The shoulder then rose to a point 3.04 inches below the starting position and while the horizontal position remained constant climbed another .21 inches. From that point, 4.93 inches behind and 3.25 inches above the starting position, displacement was forward for .36 seconds. During that time the shoulder moved 5.35 inches to a point .42 inches in front of the starting position. For the .12 seconds before release and for the remainder of the analysis, the shoulder moved backward. At release the shoulder was .21 inches behind its starting position. From the point 3.25 inches above the starting position, vertical displacement was erratic until .20 seconds before release. During the .20 seconds period preceding release, the shoulder rose 2.62 inches to a release point .94 inches below the starting position. At the beginning of the follow through, the shoulder moved downward. Pre-release ROM was -5.88 inches to .42 inches horizontally and -3.5 inches to 1.68 inches vertically.

During the first .36 seconds, the shoulder was usually accelerating; velocity increased from .69 ft/s to the maximum velocity of 11.85 ft/s. In the next .04 seconds the joint decelerated rapidly to a velocity of 4.15 ft/s. The joint continued to decelerate rapidly to a velocity of 1.87 ft/s. For the remainder of the throw, velocity fluctuated due to short bursts of acceleration and deceleration. Maximum acceleration and deceleration, which occurred within .08 seconds of each other in the recovery phase, were 202.22 ft/s^2 and 192.54 ft/s^2 respectively.

Except for two .04 second periods, the elbow moved backwards for .72 seconds to a point 21.09 inches behind the starting position. Apparent forward displacement may have been due to digitizing error as the distances were .31 inches and .52 inches respectively. For the next 0.08 seconds, the elbow moved horizontally within a .73 inch range. It then began a forward displacement which lasted throughout the remainder of the analysis. The vertical displacement was not as consistent as the horizontal. The elbow moved upward for .28 seconds to a point 3.15 inches above the starting position, dropped 2.20 inches in .12 seconds, then fluctuated within a 5.77 inch range for .32 seconds. The elbow was then 4.51 inches above the starting position and at its point of greatest backward displacement. In .04 seconds the elbow dropped 1.72 inches then rose for .44 seconds to a point 16.05 inches above the starting position. From there the elbow descended for the remainder of the analysis. The elbow attained its greatest vertical displacement .04 seconds before release. At release the elbow was 2.83 inches ahead of and 14.17 inches above its starting position. Pre-release ROM was -21.09 inches to 2.83 inches horizontally and -1.26 inches to 16.05 inches vertically.

During the throw there was one .16 second period of acceleration. No other period of acceleration nor any period of deceleration lasted longer than .08 seconds. The .16 second period of acceleration occurred approximately half way through the power phase. The maximum velocity of 11.01 ft/s occurred .22 seconds before release. Maximum acceleration and deceleration were 111.56 ft/s^2 and 185.59 ft/s^2 respectively.

For the first .12 seconds of the analysis the wrist moved forward 1.36 inches and up 3.04 inches. Movement continued upward for .24 seconds to a point 13.64 inches above the starting position. Vertical displacement, although gradually upward to a point 21.93 inches above the starting position, fluctuated for the next .60 seconds. The wrist reached its maximum vertical displacement, 29.17 inches, .20 seconds later. During the following .08 seconds, the joint descended 7.45 inches to a release point 21.72 inches above the starting position. After the initial forward displacement, the wrist moved backward 2.41 inches and forward 1.26 inches before beginning a backward displacement that lasted .44 seconds. At the end of that time, the wrist was 23.19 inches behind the starting position. The wrist then moved forward .21 inches and back .52 inches in .08 seconds. The wrist, which had reached its maximum backward displacement of 23.50 inches, moved forward for the remainder of the analysis. From the point of maximum backward displacement, the wrist moved forward 32.84 inches in .44 seconds to a point 9.34 inches in front of the starting position. Pre-release ROM was -23.50 inches to 9.34 inches horizontally and 0.00 inches to 29.17 inches vertically.

There was one .12 second period of acceleration which started .24 seconds after the beginning of the analysis. During that .12 second period, the wrist accelerated from a velocity of 4.37 ft/s to a velocity

of 11.64 ft/s. In the next .04 seconds the joint achieved its maximum deceleration of 255.89 ft/s² and slowed to a velocity of 1.40 ft/s.

From this time until .12 seconds preceeding release, no period of acceleration or deceleration exceeded .08 seconds. From .12 seconds prior to release throughout the remainder of the analysis, the wrist decelerated from its maximum velocity of 10.65 ft/s. Maximum acceleration of the wrist was 340.52 ft/s².

Throw 4

Average force during power phase	2.3033 pounds	
In flight horizontal ball velocity	26.0144 ft/s	
Range of Motion (in inches)	Horizontal	Vertical
Shoulder	4.4069	8.1845
Elbow	24.1343	20.5667
Wrist	30.1155	33.9978

Except for a pause, which occurred at the transition between the recovery and power phases, the throw was essentially smooth. Initial motions were trunk extension, shoulder flexion and abduction, and elbow flexion. The arm was then abducted and the elbow flexed to approximately ninety degrees. Shoulder flexion and rotation brought the ball to a position approximately level with the head. Horizontal extension and rotation then brought the ball behind the head. At the end of the recovery, the wrist was hyperextended and the hand was directly under the ball. The elbow led during the power phase which included the motions of trunk rotation, shoulder and elbow extension, and wrist flexion. At release, the arm, which formed approxametly a 135 degree angle at the shoulder, was in a straight line through the finger tips. The actions of the follow through were trunk flexion, trunk rotation, shoulder extension and adduction, and wrist flexion.

In the first .04 seconds the ball moved forward 1.99 inches and down 2.62 inches. In the next .04 seconds the ball moved straight up 3.45 inches. The ball moved forward for another .08 seconds then backward for .76 seconds to its maximum displacement of 22.98 inches. Horizontal motion was forward for the remainder of the analysis. From the -2.62 inches position, the ball moved upward 26.92 inches in .36 seconds. Vertical displacement then fluctuated within a 4.09 inch range for .32 seconds. During the .12 second period in which the ball moved backward from -21.41 inches to -22.14 inches, the ball remained at a level 25.92 inches above the starting position. The ball rose for .16 seconds, dropped 1.57 inches .08 seconds after it started forward, rose 7.24 inches in .08 seconds, dropped 2.41 inches in .04 seconds, rose 8.08 inches to its maximum vertical displacement of 39.35 inches in the next .04 seconds, then dropped for the remainder of the analysis. Maximum vertical displacement occurred .04 seconds before release. At release the ball was 13.01 inches in front of and 38.51 inches above its starting position.

Due to short periods of acceleration and deceleration, velocity was constantly fluctuating until the ball began a downward path .12 seconds before release. Average velocity (7.78 ft/s) was much greater in the early recovery phase than in the late recovery and early power phases (1.40 ft/s). Sixteen hundredths of a second before release, the ball accelerated rapidly from 3.82 ft/s to 10.37 ft/s. It slowed to 9.84 ft/s in the next .04 seconds then accelerated through the remainder of the analysis. Release velocity was 26.07 ft/s.

The average linear force imparted to the ball during the power phase, which was approximately .20 seconds, was 2.30 pounds.

At no time did vertical displacement of the shoulder continue in the same direction for more than .12 seconds. Horizontal displacement

was as erratic as vertical displacement except for a .28 second period which ended .08 seconds before the ball reached its maximum backward displacement. During the .28 second period, the shoulder moved backward from 1.46 inches behind the starting position to 3.88 inches behind the starting position. During that period of backward displacement, vertical displacement was primarily upward from a point 6.09 inches below the starting position to a point 2.20 inches below the starting position. There was no apparent correlation between horizontal and vertical displacement. At release the shoulder was 1.99 inches behind and 1.15 inches below the starting position. Pre-release ROM was -3.88 inches to 0.52 inches horizontally and -8.19⁽¹⁷⁾ inches to 0.00 inches vertically.

The shoulder was constantly alternating between acceleration and deceleration with the longest period of each being .16 seconds. During the .28 second period of backward displacement, the joint was usually decelerating resulting in a loss of velocity of 3.40 ft/s. As the ball reached its maximum backward displacement and started forward, the shoulder began its only .16 period of acceleration. During this transition, velocity increased from 1.24 ft/s to 6.16 ft/s. The maximum velocity of 12.91 ft/s was attained .04 seconds before release. Release velocity was 3.72 ft/s. Maximum acceleration and deceleration were 230.07 ft/s² and 229.72 ft/s² respectively. Maximum deceleration occurred .08 seconds after maximum acceleration.

With the exception of two .04 second periods in which the elbow moved downward, the path of the elbow was back and up for .48 seconds. At the end of that .48 second period, the elbow was 17.94 inches behind

(17) The joint dropped sharply to this vertical coordinate which may be a piece of faulty data. However, as the ball, elbow, and wrist had similar drops at the same time and as the horizontal coordinate was logical, the point is probably reasonably accurate.

and 6.82 inches above its starting position. The elbow then moved forward 1.68 inches and down 4.94 inches in .08 seconds. For the next .24 seconds motion was again back and up to a point 20.46 inches behind and 9.13 inches above the starting position. Horizontal displacement did not change for .04 seconds then the elbow moved forward until after the release of the ball. The elbow started forward .04 seconds before the ball did. Vertical displacement continued upward for .16 seconds then the joint dropped 1.47 inches in .04 seconds. The elbow resumed an upward path for .08 seconds then dropped 5.88 inches in .04 seconds and rose 6.61 inches in .04 seconds. From the point of maximum vertical displacement, 16.69 inches above the starting position, the elbow descended .84 inches to the point of release then continued to descend for the remainder of the analysis. At release the elbow was 0.00 inches ahead of and 15.84 inches above the starting position. Pre-release RCM was -20.46 inches to 0.00 inches horizontally and -3.88 inches to 16.68 inches vertically.

The majority of the periods of acceleration or deceleration were 0.04 to 0.08 seconds in duration. However, as the elbow started forward it accelerated for .20 seconds from a velocity of 1.53 ft/s to a velocity of 10.98 ft/s. The elbow reached its greatest pre-release velocity, 13.77 ft/s, .04 seconds prior to release. At release velocity was 2.63 ft/s. The greatest velocity attained during the analysis, 20.64 ft/s, occurred .08 seconds after release. Maximum acceleration and deceleration were 389.37 ft/s^2 (18) and 278.54 ft/s^2 respectively.

For the first .24 seconds, horizontal displacement of the wrist was erratic, while; after an initial downward displacement of 2.52

(18) This occurred after release.

inches, vertical displacement was upward. At that point, the wrist was 2.52 inches behind and 13.54 inches above the starting position. As the wrist started backward it dropped .84 inches. Vertical displacement was then erratic for .28 seconds. Horizontal displacement continued backward as the wrist rose for .24 seconds. At one time during the backward ascent, the wrist did not move for .04 seconds. The wrist was then 21.51 inches behind and 21.72 inches above the starting position. In the next 0.04 seconds, the wrist's displacement was vertical 0.52 inches. In the next .08 seconds, the wrist moved forward then back to its greatest horizontal displacement of 21.62 inches. After reaching its greatest backward displacement, the wrist moved forward until after release. From the .52 inch vertical ascent, the wrist continued upward for .12 seconds then fluctuated for .24 seconds reaching its maximum vertical displacement of 31.48 inches above the starting position .04 seconds before release. The wrist then dropped 4.41 inches to the point of release and continued to drop for the remainder of the analysis. At release the wrist was 3.04 inches in front of and 27.07 inches above the starting position. Pre-release ROM was -21.51 inches to 3.04 inches horizontally and -2.52 inches to 31.48 inches vertically.

Velocity was irregular due to short alternating periods of acceleration and deceleration. Except for one .12 second period of acceleration and one .12 second period of deceleration, periods of acceleration and deceleration were .04 to .08 seconds in duration. The .12 second period of deceleration, during which wrist velocity dropped from 7.24 ft/s to 0.00 ft/s, occurred near the end of the recovery phase. The .12 second period of acceleration occurred as the wrist started forward in the power phase. Maximum velocity, 17.69 ft/s, occurred .04 seconds before release. Release velocity was 15.65 ft/s. Maximum acceleration and deceleration,

both of which occurred during recovery, were 226.15 ft/s^2 and 239.73 ft/s^2 respectively.

Comparison by throw

	Least		Greatest	
Average force during power phase	1 (.56 sec.)		4 (.20 sec.)	
In flight horizontal ball velocity	2		4	
Range of Motion	<u>Hor</u>	<u>Vert</u>	<u>Hor</u>	<u>Vert</u>
Shoulder	4	3	3	4
Elbow	2	2	3	4
Wrist	2	2	3	4
<u>Averages</u>	Pre		Post	
Force during power phase (in pounds)	0.74		2.13	
In flight horizontal ball velocity	12.64 ft/s		21.39 ft/s	
Displacements in inches				
Shoulder				
Horizontal	5.15		5.35	
Vertical	6.16		6.72	
Elbow				
Horizontal	12.71		22.19	
Vertical	10.29		18.94	
Wrist				
Horizontal	23.97		28.70	
Vertical	13.88		31.58	

With Subject 2, the two post throws showed greater application of force during the power phase and greater in flight horizontal ball velocity than did the two pre throws. However, although greater force and greater horizontal ball velocity correlate in the post throws there two parameters do not correlate in the pre throws. The average force applied

applied during the power phase increased as the length of the power phase decreased.

The only displacement parameters that correlated with the greatest application of force and the greatest in flight horizontal ball velocity were those of vertical displacement at all joints.

With Subject 2 all parameters measured showed an average increase after water exercise. In all throws the information on the shoulder will be the least accurate because of the difficulty in pinpointing the joint center. There were times when the tape indicating the landmark was difficult to see.

Figure 2 shows the starting position, a mid-point recovery position, the position, as nearly as could be determined visually, when the ball reached its maximum backward displacement, a position midway through the power phase, the point of release, and a position near the end of the follow through. This figure shows the difference in performance between the pre and post trials. The pre water exercise trials were pushing motions during which the ball never rose above the subjects head. The post water exercise trials were throwing actions. Figure 2 shows the increased ROM which occurred at the shoulder after water exercise. Note also the trunk rotation in the post exercise throws.

Graphs IIA-IID show the displacement of the ball, shoulder, elbow, and wrist for throws one and four which were the pre and post throws with the greatest in flight horizontal ball velocity. The x indicates the starting point for each throw and the position at release is underlined. With Graph IIA note the greater post release slope of the pre throw. This is indicative of the downward application of force which was applied to the pre throw as compared with the more horizontal application of the force in the post throw. Graph IIB shows that

although shoulder displacement was approximately the same for the pre and the post trial graphed, the direction of the displacement was not the same. Graph IIC shows two things when used in conjunction with Figure 2. Note the downward displacement of the elbow in throw one and the upward displacement of the elbow in throw four. Note also the more expansive motion in the post exercise throw. Graph IID shows a great increase in the vertical displacement of the wrist and an increase in backward displacement of the wrist. Horizontal displacement shows the later release of the ball in the pre exercise throw. Due to the later release, forward displacement appears to be less, but this is due to an earlier recovery.

For this subject the post activity throws were definitely superior. Throw four was the best in both appearance and effectiveness.

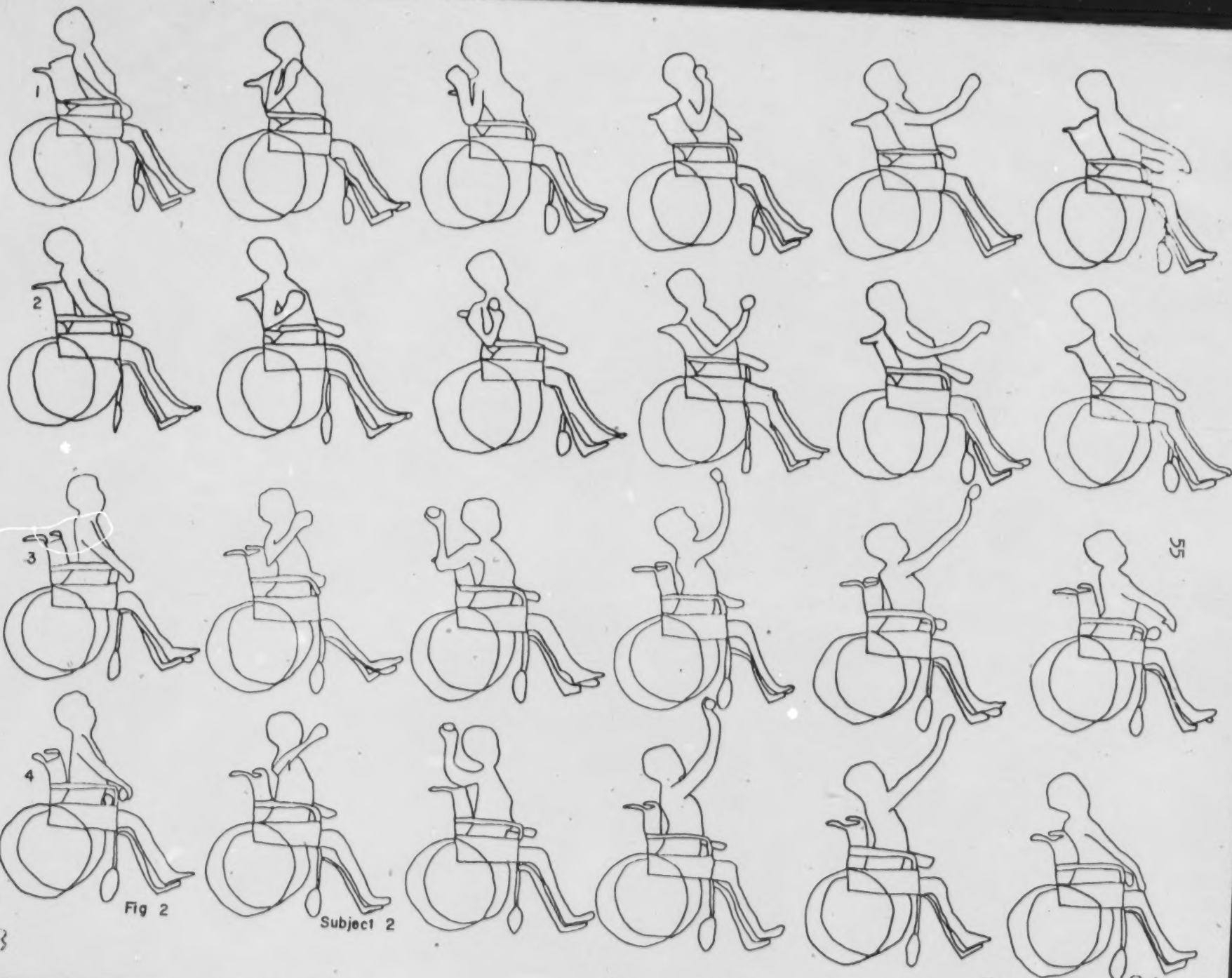
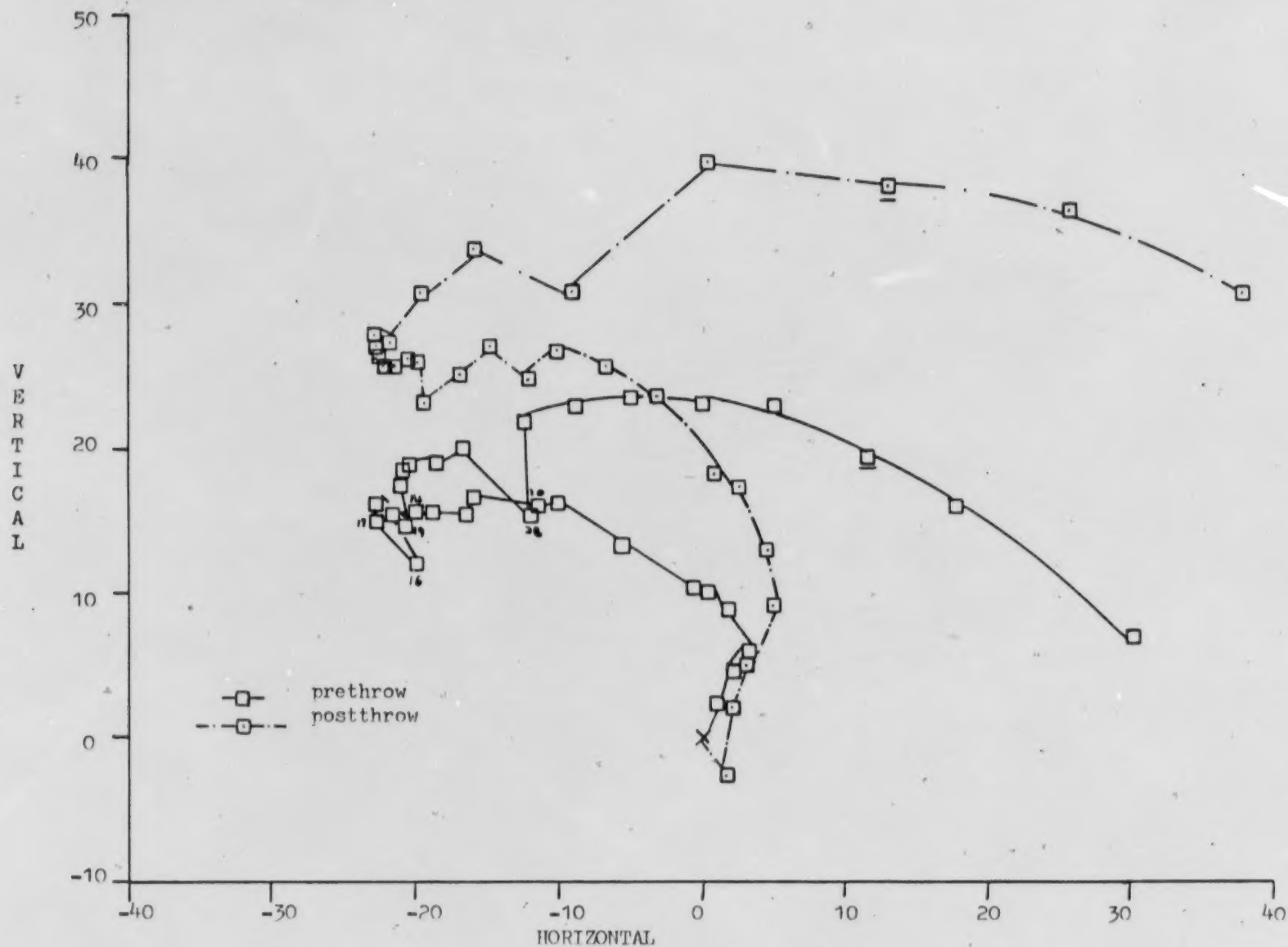


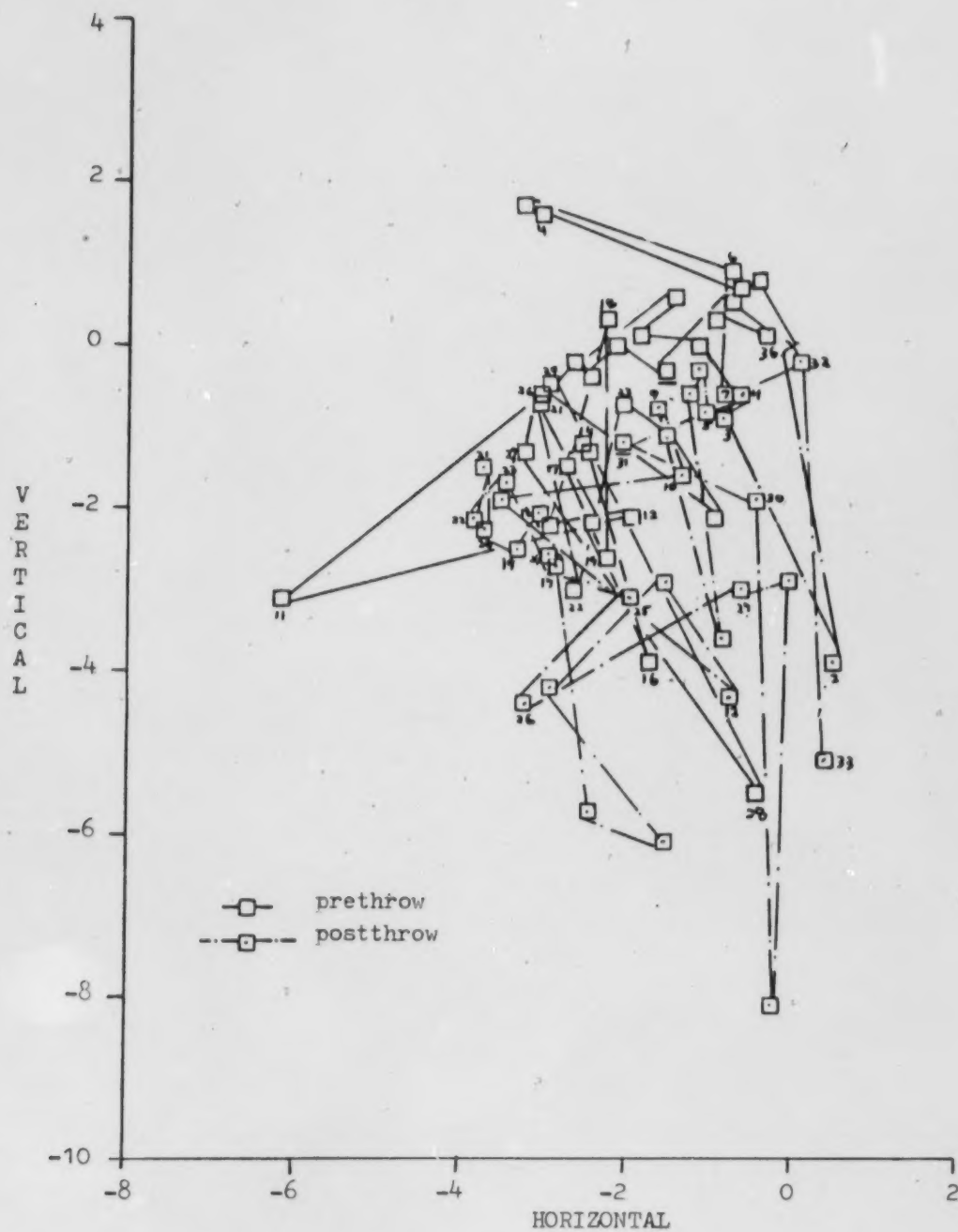
Fig 2

Subject 2

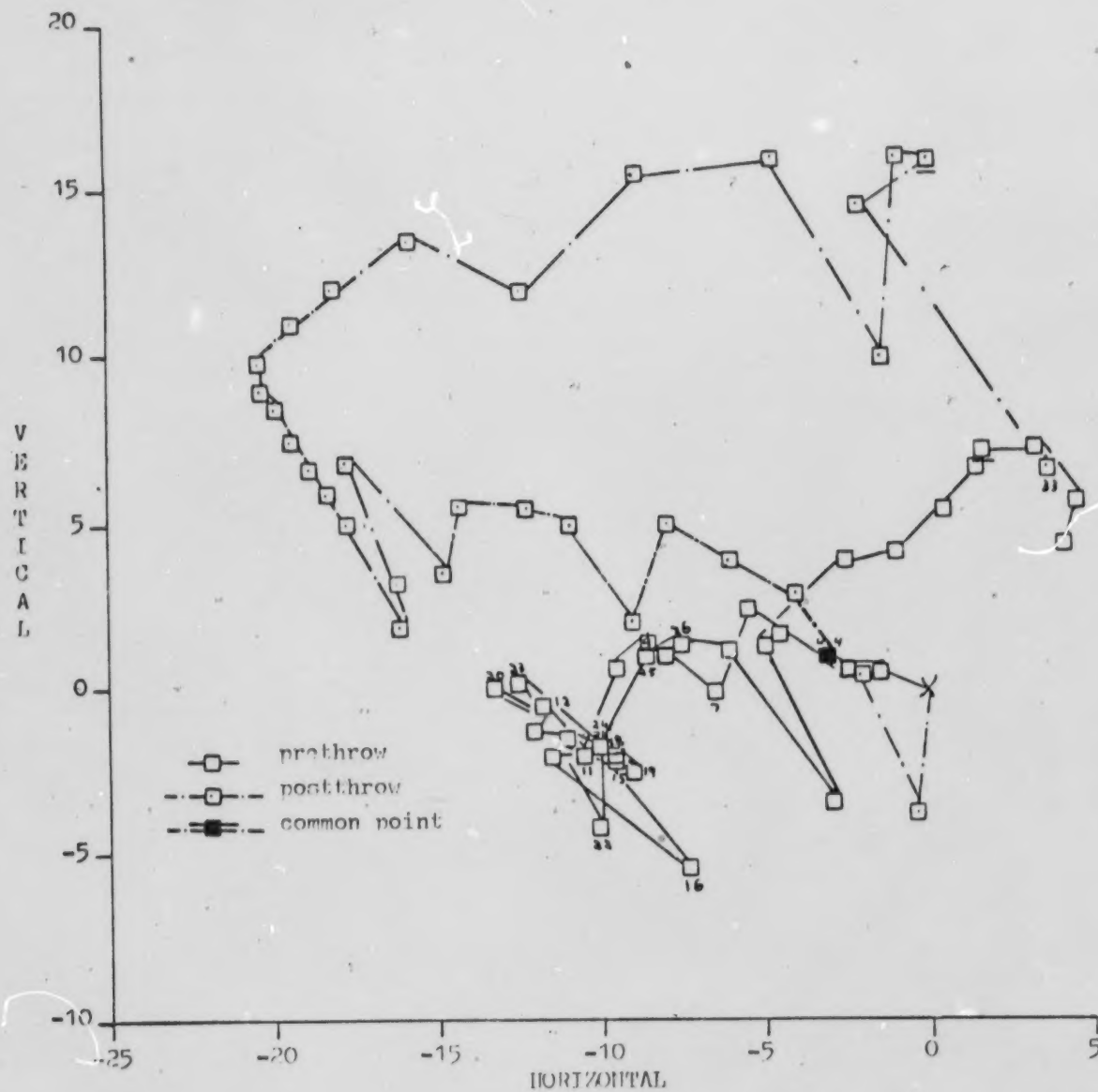
GRAPH IIA SUBJECT 2 THROWS 1 AND 4 BALL DISPLACEMENT IN INCHES



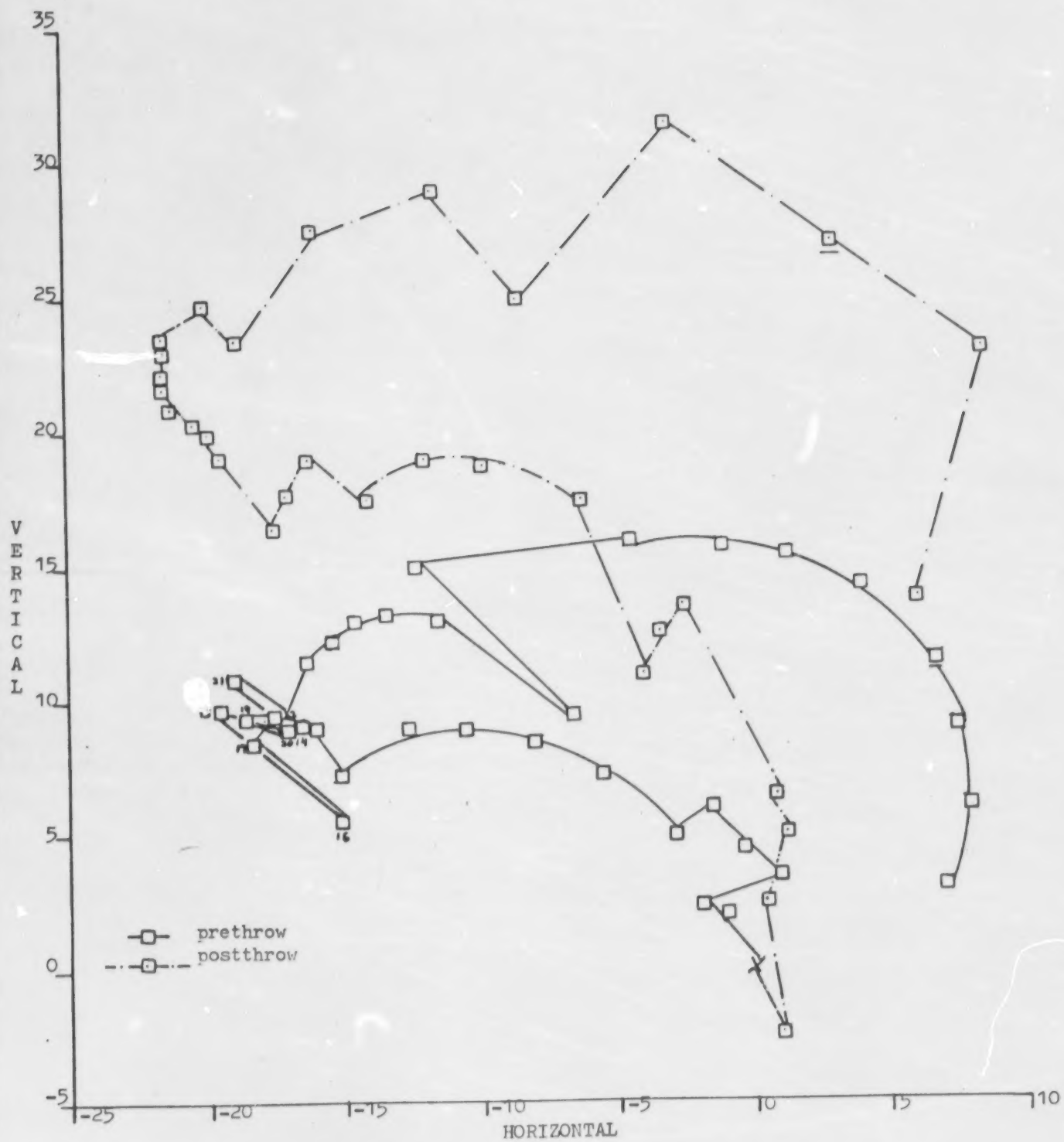
GRAPH IIB SUBJECT 2 THROWS 1 AND 4 SHOULDER DISPLACEMENT IN INCHES



GRAPH IIC SUBJECT 2 THROWS 1 AND 4 ELBOW DISPLACEMENT IN INCHES



GRAPH IID SUBJECT 2 THROWS 1 AND 4 WRIST DISPLACEMENT IN INCHES



SUBJECT III

Throw 1

Average force during power phase	3.2691 pounds	
In flight horizontal ball velocity	19.5266 ft/s	
Range of Motion (in inches)	Horizontal	Vertical
Shoulder	7.5052	10.3532
Elbow	21.1419	22.9386
Wrist	20.9301	28.7523

Rather than a throw, the action of this trial was a push. There was spasticity in the action particularly around the transition between the recovery and power phases. During the transition there was back and forth motion in a confined area slightly in front of the subject's head. During recovery the right elbow was drawn back, the left arm was abducted and flexed at the shoulder, the trunk rotated toward the right and the neck hyperextended. These actions were followed by an abduction of the right arm to an approximately ninety degree angle with the shoulder and downward rotation which caused the forearm to be angled downward. The elbow was flexed to approximately ninety degrees. The wrist hyperextended slightly. The neck continued to hyperextend. Shoulder rotation brought the ball up to chin level at which time the wrist was hyperextended and the arm was almost parallel to the floor. The ball continued upward due to abduction. At this time the trunk had rotated to the normal and the left arm had dropped. Trunk action was then backward while there was horizontal flexion and elbow flexion which pushed the ball forward and very slightly up to release. In the follow through the right arm crossed the body and the trunk rotated slightly toward the left.

For the first 1.32 seconds of the analysis, horizontal displacement of the ball was erratic. The longest period of time in which the ball moved in the same horizontal direction was .16 seconds and there were only three of these. For the most part the ball continued in the same horizontal direction for only .04 seconds. There were four .04 second periods when the ball did not displace horizontally. Maximum forward displacement during this time was to a point 4.76 inches in front of the starting position and maximum backward displacement was to a point 5.39 inches behind the starting position. For the majority of the first 1.12 seconds of that period the ball was in front of the starting position and for all of the remaining .80 seconds the ball was behind the starting position. The ball, which was then 3.38 inches behind and 17.76 inches above the starting position, moved forward for the remainder of the analysis. Vertical displacement was just as erratic for the first .88 seconds with the vertical direction of the ball changing almost every .04 seconds but generally remaining within .50 inches of the starting position. The ball was then raised 12.16 inches in .36 seconds to a point 12.16 inches above the starting position. The ball then dropped 3.49 inches in .04 seconds, rose 7.51 inches in .04 seconds, and continued to rise for another .12 seconds to a point 17.86 inches above the starting position. From here displacement was generally downward for .28 seconds and then generally upward for .36 seconds. At that time the ball had attained its greatest vertical displacement, 23.89 inches above the starting position, and descended for .04 seconds to the point of release. At release the ball was 20.61 inches in front of and 21.67 inches above the starting position. There was no correlation between forward and vertical motion, however; when the ball moved backward, it usually moved upward.

There were alternating periods of acceleration and deceleration, which never exceeded .12 seconds and .16 seconds respectively, throughout the first 1.92 seconds of the analysis. As the ball started forward, it began to accelerate and continued to do so for the remainder of the analysis. Release velocity was 19.92 ft/s.

No upward force was imparted to the ball at release. The average linear force imparted to the ball during the power phase, which lasted approximately .10 seconds, was 3.27 pounds.

For the first .24 seconds, horizontal motion of the shoulder was forward and vertical motion was erratic. At the end of the time the shoulder was 1.59 inches in front of and 1.27 inches above its starting position. Motion was erratic in both planes for the next .20 seconds. For the last .04 seconds of the period the shoulder had no vertical displacement. In the next .04 seconds, the shoulder moved forward and up. In the next .08 seconds, the shoulder moved up 1.90 inches and down 1.59 inches; it did not move horizontally. The shoulder's horizontal displacement was erratic for the remainder of the throw with four .04 second periods of no movement and with .12 seconds being the longest period of continuous displacement in any horizontal direction. Vertical displacement was downward 1.80 inches in .04 seconds, upward 1.27 inches in .20 seconds, and downward .42 inches in .08 seconds. It did not displace vertically in the next .04 seconds. Vertical motion was upward 2.11 inches in .16 seconds and downward 8.35 inches in .16 seconds. Vertical motion then became more erratic for the remainder of the throw with one .04 seconds and one .08 second period of no vertical displacement. The .08 second period occurred just before release. At one time, .12 seconds before the ball started forward to release, there was no shoul-

der motion in either plane. There was no correlation between horizontal and vertical motion. At release the shoulder was .63 inches in front of and 4.44 inches above its starting position. Pre-release ROM was -3.59 inches to 2.01 inches horizontally and -4.44 inches to 5.60 inches vertically.

Velocity of the joint ranged from a low of 0.00 ft/s at the point of no displacement to a high of 15.07 ft/s as the shoulder dropped to its lowest point during the throw. At release velocity was 3.75 ft/s. Periods of acceleration and deceleration lasted from .04 to .12 seconds except for one .20 second period of acceleration very early in the action. During the .20 second period, velocity of the joint increased from 4.41 ft/s to 15.07 ft/s, the greatest velocity of the throw. Maximum acceleration and deceleration were 205.71 ft/s^2 and 291.38 ft/s^2 respectively.

For the first .40 seconds, movement of the elbow was erratic in both planes. In the next .04 seconds the elbow moved forward 2.33 inches; it did not move vertically. The elbow was then 3.28 inches in front of and 3.28 inches above the starting position. In the next .04 seconds, the elbow moved forward 1.69 inches and down 3.70 inches. During the next .64 seconds, the elbow moved up 18.71 inches. For the first .24 seconds, of that time, the elbow's horizontal motion was erratic; it then moved backward 6.03 inches. The elbow was then 4.33 inches behind and 11.73 inches above the starting position. In the next .04 seconds, the elbow moved forward .11 inches; it did not move vertically. Movement was erratic in both planes for .28 seconds. During the .28 second period, there were two .04 second periods in which there was no vertical displacement. In the next .16 seconds, the elbow moved forward .85 inches, back .32 inches, and forward .95 inches. The elbow continued forward

until after release while vertical displacement continued to be erratic. The elbow reached its highest displacement, 15.33 inches above the starting position, .28 seconds before release. It remained at that height until .08 seconds before release. At release the elbow was 4.02 inches in front of and 9.94 inches above its starting position. Pre-release ROM was -7.40 inches to 13.74 inches horizontally and -6.98 inches to 15.97 inches vertically.

Until .04 seconds after the elbow started forward in the power phase, velocity of the joint was usually very slow averaging 3.31 ft/s. Included within this average were the three greatest velocities of the throw, 18.32 ft/s, 14.10 ft/s and 13.80 ft/s. All three of these velocities were due to large vertical displacements. In the power phase, the average velocity was 8.16 ft/s. Velocity at release was 4.95 ft/s. The elbow repeatedly accelerated and decelerated throughout the throw with an alteration every .04 seconds for the final .76 seconds. The 0.76 second period included part of the recovery phase and all of the power phase. Maximum acceleration and deceleration were 303.29 ft/s^2 and 393.45 ft/s^2 respectively.

In the first .04 seconds, the wrist moved backward .21 inches and up 1.69 inches. The wrist then moved forward .42 inches in .08 seconds, did not move for .04 seconds and continued forward 1.80 inches in the next .08 seconds. During that time vertical motion was erratic with a net backward displacement of 3.28 inches. For the next .36 seconds, motion was erratic in both planes. The wrist was then 2.22 inches in front of and 2.33 inches above the starting position. The wrist moved backward 4.65 inches in the next .44 seconds. During that time the joint moved down .53 inches in .04 seconds then rose 6.13 inches. In the next .04 seconds the wrist continued upward 2.11 inches but did

not move horizontally. Horizontal displacement became erratic until 0.32 seconds before release. Vertical motion was upward for another 0.04 seconds, downward for 0.08 seconds, then upward again for another 0.32 seconds. During that time the wrist rose 3.91 inches. Vertical movement was then erratic for .20 seconds after which it ascended 3.49 inches in .16 seconds. Thirty-two hundredths of a second before release the wrist was 5.71 inches behind and 19.45 inches above the starting position. The wrist then moved forward 19.66 inches to release. Vertical displacement continued to be erratic with the wrist reaching its greatest vertical displacement, 22.62 inches above the starting position, 0.08 seconds prior to release. At release the wrist was 13.95 inches in front of and 17.34 inches above the starting position. Pre-release RCM was -6.92 inches to 13.95 inches horizontally and -6.13 inches to 22.62 inches vertically.

The maximum velocity of the throw, 20.98 ft/s, occurred during the recovery phase. There was a .12 second period, late in the recovery phase where velocity was constant. During that time the wrist moved backward .42 inches and forward .21 inches while it moved upward .63 inches. The greatest power phase velocity, 14.83 ft/s, occurred .04 seconds prior to release. Velocity at release was 10.35 ft/s. Maximum acceleration and deceleration, both of which occurred in the recovery phase, were 480.50 ft/s^2 and 426.43 ft/s^2 respectively.

Throw 2

Average force during power phase	2.7060 pounds	
In flight horizontal ball velocity	27.3079 ft/s	
Range of Motion (in inches)	Horizontal	Vertical
Shoulder	8.6681	9.3023
Elbow	23.8902	18.6048
Wrist	23.2558	28.2240

The post-throw did not show the spasticity of the pre-throw. During recovery both arms abducted and the elbows flexed to approximately forty-five degrees. After approximately forty-five degrees of abduction, the left arm stopped and the right arm continued upward. When the elbow was at about the level of the shoulder, the forearm was tilted downward due to rotation of the shoulder. During this time the trunk had rotated slowly toward the right. Shoulder rotation then brought the ball above the elbow which remained at about the same level. At this point the wrist was in a hyperextended position. A combination of shoulder movements, horizontal flexion, flexion, and abduction, elbow extension, and wrist flexion carried the ball forward and up. Meanwhile the trunk has been rotating toward the left. The shoulder started to extend prior to release and the wrist was still slightly hyperextended at release. At release the left arm was in front of the body. The force imparted to the ball at release was almost directly horizontal. During the follow through, the arm continued to extend and to move laterally, the wrist continued to flex, and the trunk continued to rotate towards the left.

Much less of the preliminary action was measured for the post-throw than was measured for the pre-throw. The preliminary action was within a confined area and did not contribute to the throw.

For the first .52 seconds, the ball was moved erratically in both planes. During that time the ball was generally behind and below the starting position. Horizontal displacement ranged from -7.51 inches to 0.21 inches and vertical displacement ranged from -3.28 inches to 5.07 inches. At the end of the .52 seconds the ball was 1.80 inches behind and 1.90 inches above its starting position. During the next 0.48 seconds, the ball was moved back and up to a point 12.58 inches

behind and 26.58 inches above the starting position. For the remainder of the throw, horizontal displacement was forward. Vertical displacement continued upward until .04 seconds prior to release when the ball began to be moved downward. At release the ball was 28.33 inches in front of and 30.66 inches above the starting position.

Velocity was very irregular throughout the throw due to rapid changes in acceleration and deceleration. The longest period of acceleration, .16 seconds, occurred during the power phase and ended 0.08 seconds prior to release. During that time the velocity of the ball was increased from 1.39 feet/s to 19.50 ft/s. Eight hundredths of a second prior to release the ball was decelerated at the rate of 227.91 ft/s^2 then accelerated at the rate of 541.82 ft/s^2 . These were the greatest values for ball deceleration and acceleration which were measured during the throw. At release the velocity of the ball was 32.06 ft/s.

The average force applied to the ball during the power phase, which was approximately .14 seconds, was 2.71 pounds.

Horizontal displacement of the shoulder was erratic until .04 seconds after the ball started forward. From that time until .04 seconds after release horizontal displacement was forward. During that .24 second period, the shoulder moved forward 7.40 inches. Vertical action of the shoulder was also erratic through the early phase of the throw. Beginning .20 seconds before the ball started forward, the shoulder moved upward 2.11 inches in .16 seconds. It then dropped 4.22 inches in .08 seconds. During the time in which the shoulder moved forward 7.40 inches, it also moved upward 4.76 inches. During the last 0.04 seconds of forward displacement, the shoulder dropped 9.3 inches. (19)

(19) op cit footnote 17 This occurred just after release.

At release the shoulder was .63 inches in front of and 2.11 inches above its starting position. Pre-release ROM was -5.18 inches to 2.22 inches horizontally and -2.35 inches to 12.85 inches vertically.

During the recovery phase, shoulder velocity was very irregular ranging from .49 ft/s to 8.15 ft/s. This was due to rapid changes in acceleration and deceleration. Near the end of the recovery phase there was a .20 second period of deceleration during which the shoulder slowed from 6.06 ft/s to .44 ft/s. During the power phase, velocity continued to fluctuate ranging from 1.78 ft/s. to 6.39 ft/s. The shoulder decelerated during the .04 seconds prior to release. Velocity of the shoulder at release was 3.36 ft/s. Maximum velocity, 20.27 ft/s, occurred just after release. Maximum acceleration and deceleration, 422.75 ft/s^2 and 191.43 ft/s^2 respectively, occurred in the .08 second period following release.

During the majority of the first .88 seconds, horizontal displacement of the elbow was backward. During that time, it reached its maximum backward displacement of 10.99 inches where it remained for .04 seconds. During that time vertical displacement was erratic, though primarily upward for .72 seconds. At the end of the .72 seconds the elbow was 9.41 inches behind and 14.27 inches above the starting position. The elbow moved downward for the remainder of the first .88 seconds. It was then 10.99 inches behind and 11.31 inches above the starting position. During the next .04 seconds, the elbow moved forward .74 inches and down .42 inches. It then moved back .42 inches and up 3.60 inches. During the power phase, the elbow moved forward 18.50 inches in .24 seconds then moved backward 2.43 inches at release. For the first .04 seconds of that time, the elbow dropped 3.38 inches; it then ascended 5.18 inches during the remaining .24 seconds of the power phase.

At release the elbow was 5.39 inches in front of and 16.28 inches above the starting position. Pre-release ROM was -10.99 inches to 7.82 inches horizontally and -2.33 inches to 16.28 inches vertically.

Elbow velocity fluctuated widely during all phases of the throw. It ranged from .49 ft/s to 11.94 ft/s during the recovery phase and from 3.11 ft/s to 10.69 ft/s during the power phase. The minimum velocity during the power phase occurred .04 seconds prior to release. There were two .12 second periods of acceleration and two .12 seconds periods of deceleration during the throw; all other periods of either acceleration or deceleration were .08 seconds or less. Velocity at release was 5.23 ft/s. Maximum velocity, acceleration, and deceleration, all of which occurred immediately after release, were 25.77 ft/s, 513 ft/s², and 458.67 ft/s² respectively.

During the first .08 seconds, the wrist moved forward 2.43 inches and down 3.91 inches. During the next .20 seconds horizontal movement was backward 2.01 inches. For the first .04 seconds of that time, vertical motion continued downward .21 inches after which the wrist moved upward for .08 seconds then downward for .08 seconds for a net upward gain of 1.90 inches. During the next .04 seconds, the wrist moved forward .63 inches and down 2.01 inches; it was then 1.06 inches in front of and 4.23 inches below the starting position. For the next 0.12 seconds, horizontal displacement was backward 2.64 inches during which time the wrist moved upward for .03 seconds and downward for .04 seconds for a net upward displacement of 4.65 inches. Vertical motion was then upward until .12 seconds prior to release. During that period of vertical displacement, the wrist moved upward 23.57 inches. Horizontal displacement was forward for .08 seconds, backward for .12 seconds, forward for .04 seconds then backward for .20 seconds to the

point of greatest horizontal displacement, 9.30 inches behind the starting position. At that time the wrist was 19.45 inches above the starting position. The wrist then moved forward until .08 seconds after release. At its apex, the wrist was 24.00 inches above and 3.07 inches in front of its starting position. From that point the wrist descended 7.40 inches to a release point 11.94 inches in front of and 16.60 inches above its starting position. Pre-release ROM was -9.30 inches to 11.94 inches horizontal and -4.23 inches to 24.00 inches vertically.

During recovery wrist velocity ranged from .62 ft/s to 9.42 ft/s. There was only one period of acceleration and one period of deceleration which was .08 seconds in duration; all other periods of acceleration and deceleration were .04 seconds in length. As the wrist started forward, its velocity was 3.48 ft/s. In .04 seconds it decelerated to 1.41 ft/s after which it accelerated for .12 seconds to its maximum pre-release velocity of 11.24 ft/s. During the .12 seconds preceding release, the wrist decelerated to a release velocity of 6.51 ft/s. Maximum velocity, acceleration, and deceleration, 23.50 ft/s, 424.81 ft/s², and 395.53 ft/s² respectively, occurred immediately after release.

Comparison by throw

	Least		Greatest	
Average force during power phase	2 (.14 sec.)		1 (.10 sec.)	
In flight horizontal ball velocity	1		2	
Range of Motion	<u>Hor</u>	<u>Vert</u>	<u>Hor</u>	<u>Vert</u>
Shoulder	1	2	2	1
Elbow	1	2	2	1
Wrist	1	2	2	1
<u>Averages</u>	Pre		Post	
Force during power phase (in pounds)	3.27		2.71	

In flight horizontal ball velocities	19.53 ft/s	27.31 ft/s
Displacements in inches ⁽²⁰⁾		
Shoulder		
Horizontal	7.51	7.40
Vertical	10.04	4.97
Elbow		
Horizontal	21.14	18.82
Vertical	22.94	18.60
Wrist		
Horizontal	20.93	21.27
Vertical	28.75	28.22

In both appearance and effectiveness ⁽²¹⁾ the post exercise throw of Subject 3 was far superior to the pre exercise throw. Figure 3 shows the starting position, a mid-point recovery position, the position, as nearly as could be determined visually, when the ball reached its maximum backward displacement, a position midway through the power phase, the point of release, and a position near the end of the follow through. In Figure 3 differences between the pre water exercise throw and the post water exercise throw are clearly evident. In the pre exercise throw, which was more of a push, the arm stays low and the ball is shoved forward from the shoulder. In Figure 3.1 notice the head position at the beginning of the power phase; at that point the subject was arching his spine and hyperextending his neck. ⁽²²⁾ This same drawing shows the elbow drawn back and on the same level as the wrist; it remained behind the ball for the entire throw. Position six of the

(20) Discrepancies in values between here and the beginning of this section are due to the fact that the values in the beginning include the follow through whereas these do not.

(21) Effectiveness is measured by horizontal ball velocity.

pre throw does not show trunk rotation. In Figure 3.2 the greater upward displacement of the limb is evident. At the beginning of the power phase, the head is in a much better position. The distorted appearance of position six is due to trunk rotation which increased greatly.

The average force during the power phase was less in the post exercise throw, but this was due to the increased duration of the power phase as the horizontal velocity of the ball at release was 7.88 ft/s greater in the post exercise throw.

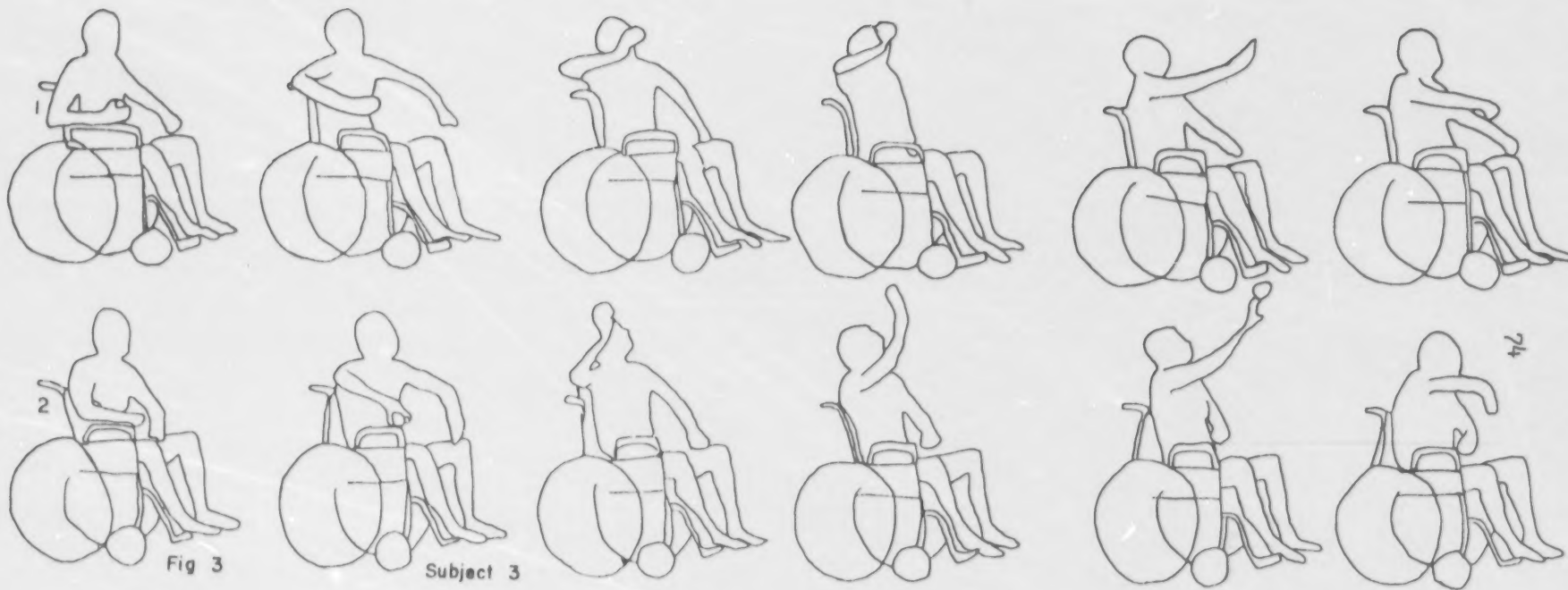
The decrease in vertical shoulder displacement was probably due to a decrease in spasticity and to an increase in efficiency. With the follow through included, as it was in the figures at the beginning of each analysis, all horizontal displacements increased and all vertical displacements decreased. With the follow through excluded, as in the figures at the end of the analysis, the only range of motion that increased was the vertical displacement of the wrist. Part of the decrease in vertical displacement may be due to the elimination of the early nonproductive motions.

In the graphs the x indicates the starting position for each throw and the position at release is underlined. Graphs IIIA and IIID clearly show the greater vertical displacement of the ball and the wrist. The greater displacement apparently occurred because of an increase in angular mobility at the shoulder. This can be seen in Figure 3.

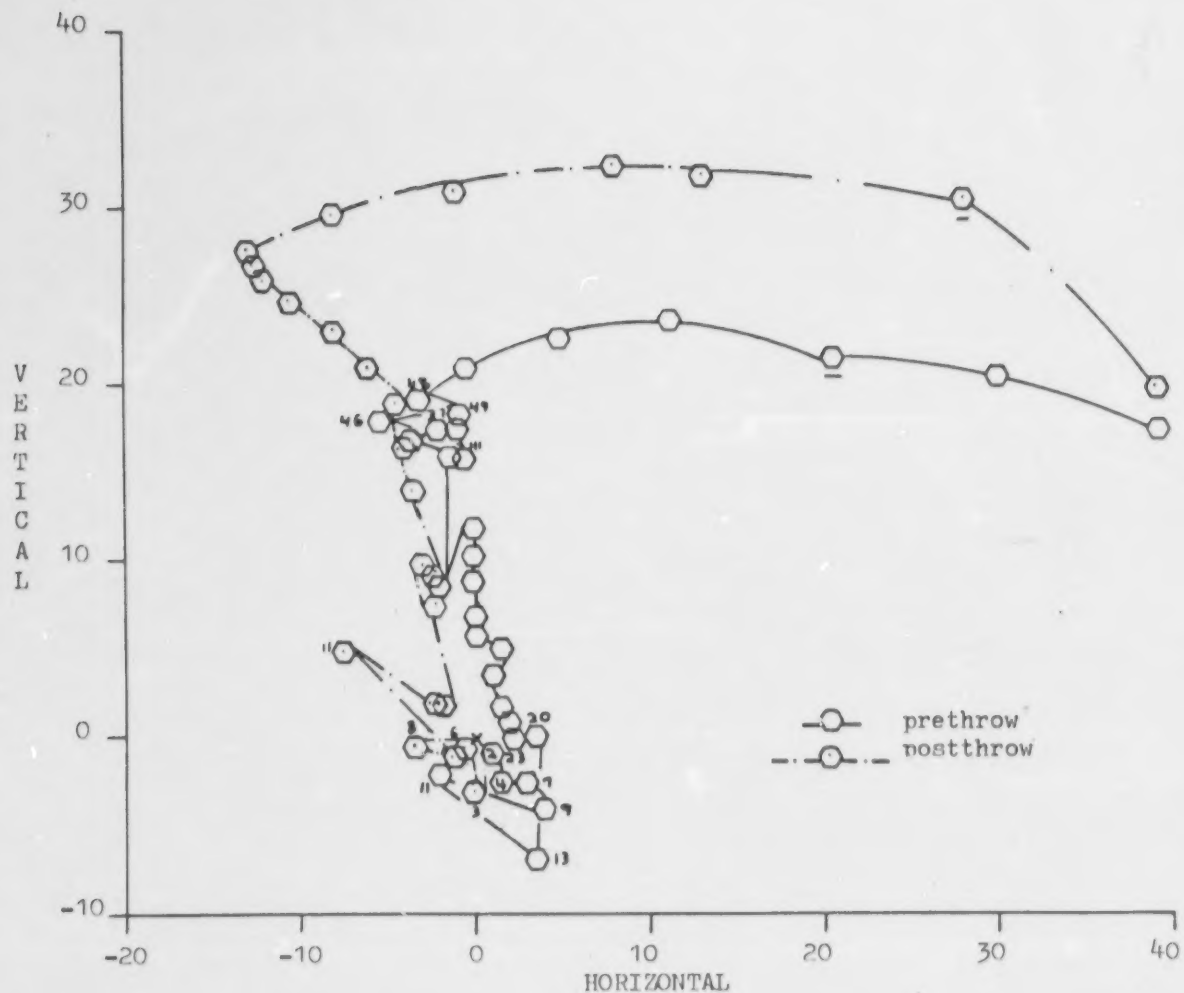
Though indications were that linear displacement decreased, inspection would indicate a greater angular displacement of the shoulder as mentioned above. There was also less arching of the trunk in

(22) The effort being expended was evident in the subject's facial expression.

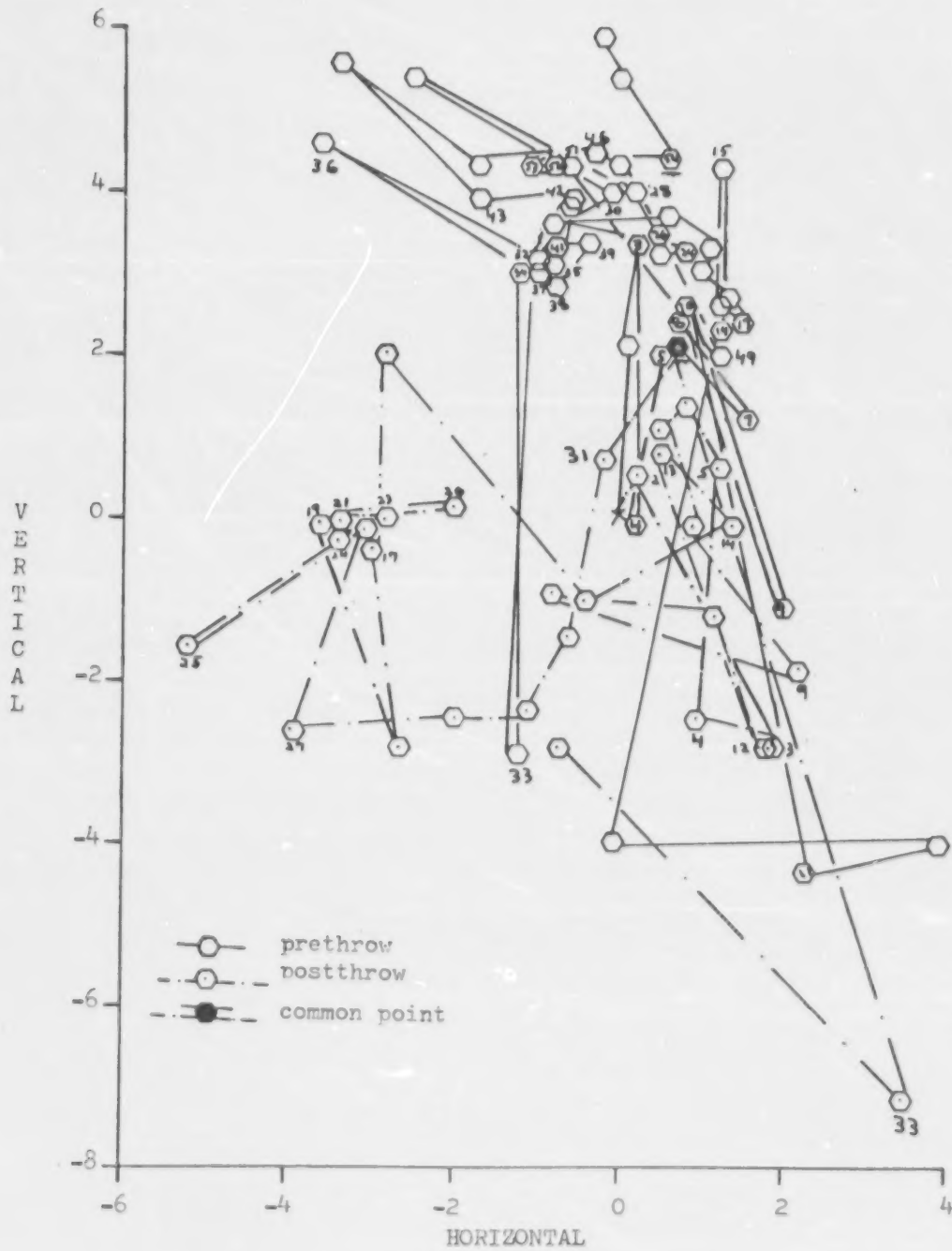
the post exercise throw which would account for part of the decrease in horizontal displacement.



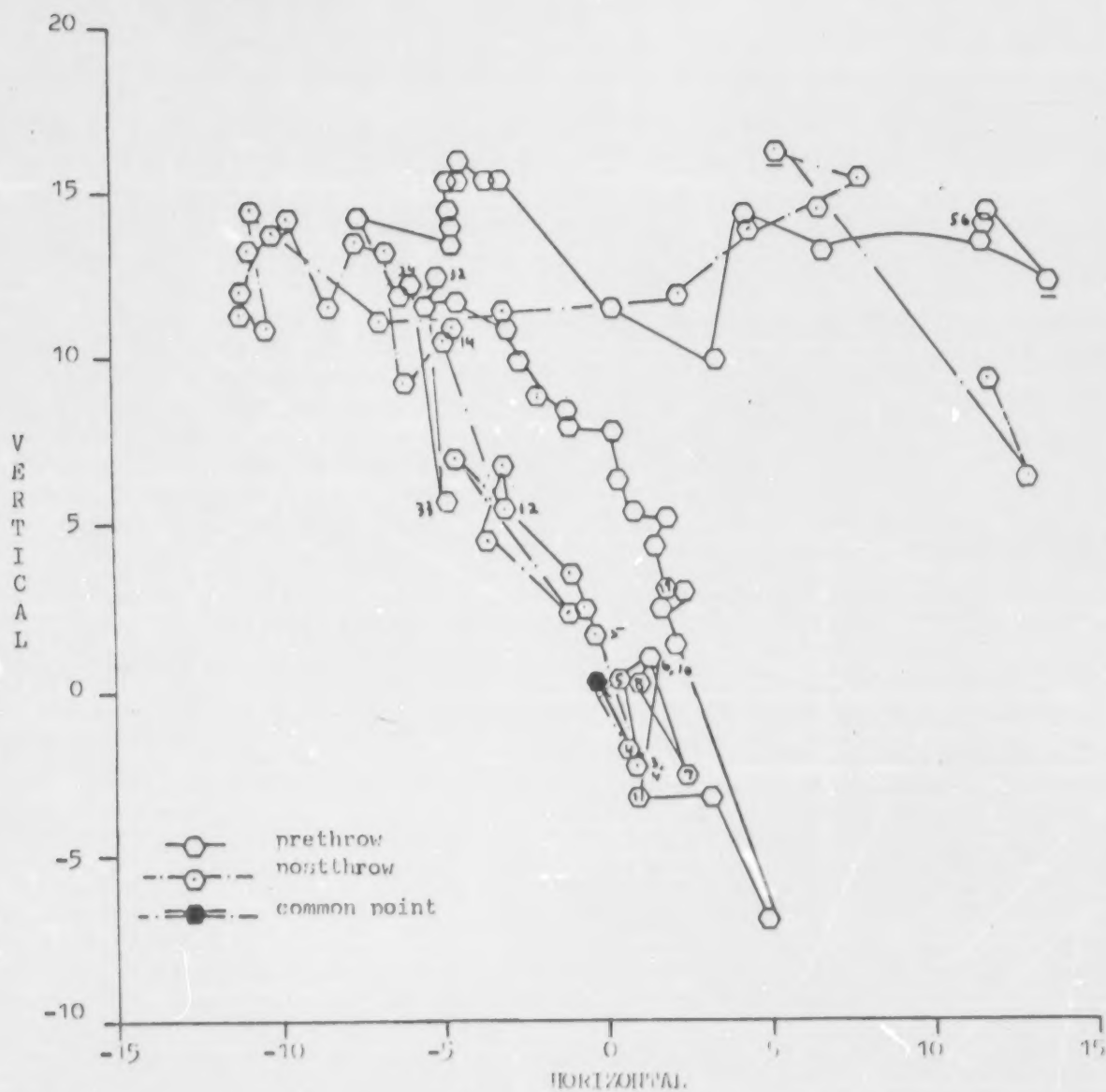
GRAPH IIIA SUBJECT 3 THROWS 1 AND 2 BALL DISPLACEMENT IN INCHES



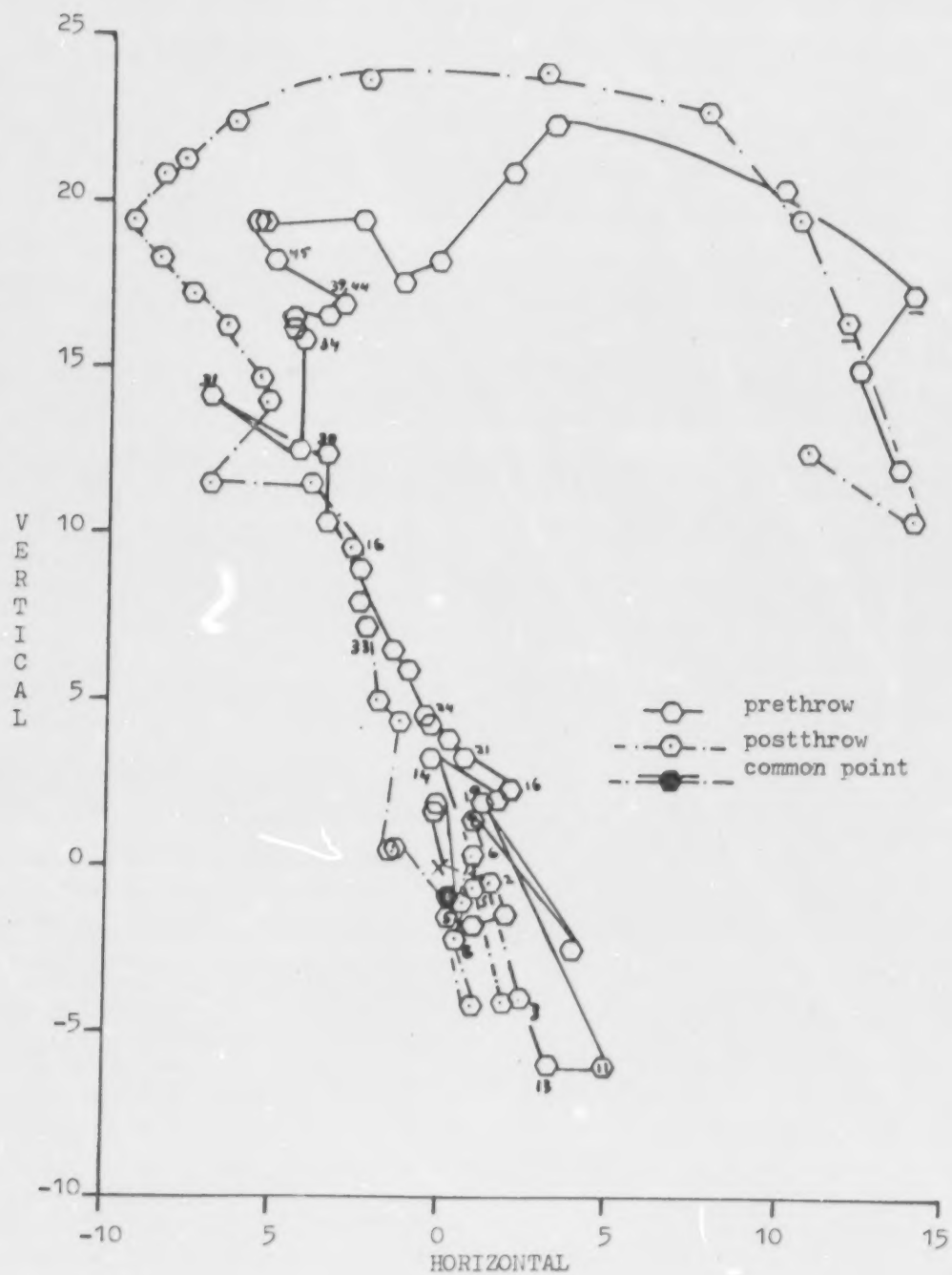
GRAPH IIIB SUBJECT 3 THROWS 1 AND 2 SHOULDER DISPLACEMENT IN INCHES



GRAPH 111C SUBJECT 3 THROWS 1 AND 2 SLOW DISPLACEMENT IN THROWS



GRAPH IIID SUBJECT 3 THROWS 1 AND 2 WRIST DISPLACEMENT IN INCHES



Cross Subject Comparisons and Statistical Results

Throughout this section the average of a subject's pre exercise throws was compared with the average of the subject's post exercise throws. Specific throws were still mentioned in the information was pertinent.

A one-way analysis of variance was used to analyze the data at the alpha - .05 level. No statistical significance was expected for any of the parameters because the number of subjects and the number of trials⁽²³⁾ were very small. The critical point, 7.71, was never approached.

Average Force During Power Phase

$\bar{x}$ ⁽²⁴⁾ pre exercise = 2.00 pounds post exercise = 2.36 pounds
 F ⁽²⁵⁾ = 0.22

With subject one, although, throw three had the smallest force, there was a slight overall increase. .25 pounds, in the post exercise trials. Both of subject two's post exercise trials were substantially more forceful than the pre exercise trials. The average increase in force for subject two's post exercise throws was 1.39 pounds which was approximately 2.88 times more forceful than the pre exercise throws. Subject three showed a decrease in force of .56 pounds. Among subjects there was an eighteen per cent increase in average force after the water exercise.

In Flight Horizontal Ball Velocities

$\bar{x}$ pre exercise = 16.14 ft/s post exercise = 22.45 ft/s
 $F = 3.81$

(23) Pre trials and post trials were averaged so that comparisons were made on pre vs post. This yielded only one degree of freedom.

(24) This is the mean value across all three subjects.

(25) This is the calculated value from Table XIII.

With subject one both post exercise throws had a greater horizontal velocity at release than either of the pre exercise throws. Subject one's average pre exercise velocity was 16.63 ft/s and the average post exercise velocity was 18.67 ft/s. With subject two, while both post exercise throws were faster than the pre exercise throws, throw four with a velocity of 26.01 ft/s was substantially faster than any of the other throws. Subject two's average pre exercise velocity was 12.64 ft/s and the average post exercise velocity was 21.39 ft/s. Subject three's pre exercise velocity was 19.53 ft/s and the post exercise velocity was 27.31 ft/s. Among subjects there was a thirty-nine per cent increase in horizontal ball velocity after the water exercise.

Horizontal Shoulder Displacement

$\bar{x}$ pre exercise = 5.93 inches post exercise = 5.57 inches

$F = 0.08$

Subject one had less horizontal shoulder displacement in both post exercise throws than in either pre exercise throw. The average decrease was 1.18 inches. With subject two, throw three had the greatest horizontal displacement of the shoulder and throw four had the least. There was an average increase of .21 inches. Subject three had a decrease of .11 inches in horizontal shoulder displacement. Among the subjects horizontal shoulder displacement decreased by six per cent. Decreases in horizontal shoulder displacement are may be due to decreases in extraneous trunk actions. As was mentioned earlier in the paper, measurements on the shoulder are the least accurate due to difficulty in digitizing the joint center.

Vertical Shoulder Displacement

$\bar{x}$ pre exercise = 6.55 inches post exercise = 6.17 inches

$F = 0.02$

While vertical displacement of the shoulder was greater in both of subject one's post exercise throws, it was substantially greater in throw four. The average increase was 5.35 inches. With subject two the horizontal displacement which occurred in throw three was less than the average horizontal displacement of throws one and two, however; the average horizontal distance increased .56 inches between the pre and post throws. Subject three showed a substantial decrease, 5.07 inches, in the post exercise throw. Among the subjects, vertical shoulder displacement increased by 4.46 per cent.

Horizontal Elbow Displacement

$\bar{x}$ pre exercise = 14.15 inches post exercise = 16.10 inches
 $F = 0.11$

Subject one had less horizontal displacement of the elbow in both pre exercise throws than in either post exercise throw for an average decrease of 1.38 inches. Subject two had substantially greater horizontal displacement of the elbow in both post exercise throws than in either pre exercise throw for an average increase of 9.48 inches. Subject three's horizontal elbow displacement decreased by 2.33 inches. Among the subjects horizontal elbow displacement increased by 13.62 per cent.

Vertical Elbow Displacement

$\bar{x}$ pre exercise = 14.21 inches post exercise = 16.48 inches
 $F = 0.21$

Subjects one and two showed increased vertical displacement of the elbow in both post exercise throws for a gain of 2.59 inches and 8.65 inches respectively. Subject three showed a decrease of 4.33 inches in vertical elbow displacement. (26) Among the subjects there was an increase of 15.98 per cent.

(26) This was probably due to a higher starting position being used.

Horizontal Wrist Displacement

$\bar{x}$ pre exercise = 21.50 inches post exercise = 23.12 inches
 $F = 0.27$

Both of subject one's post exercise throws had less horizontal displacement of the wrist than either of the pre exercise throws for a decrease of .17 inches. Subject two had a substantial increase, 4.73 inches, in the post exercise throws. Both post exercise throws had greater displacement than either pre exercise throw. Subject three had an increase of .32 inches in the post exercise throw. Among the subjects horizontal wrist displacement increased by 7.56 per cent.

Vertical Wrist Displacement

$\bar{x}$ pre exercise = 21.06 inches post exercise = 26.29 inches
 $F = 0.84$

With subject one throw three had the least vertical displacement of the wrist and throw four had the greatest for a net decrease of 1.47 inches. Subject two showed substantial increases in the post exercise throws as compared to the pre exercise throws for a net increase of 17.71 inches. Subject three's vertical wrist displacement decreased by .53 inches.⁽²⁷⁾ Among the subjects vertical displacement of the wrist increased by 24.86 per cent.

(27) Ibid

CHAPTER V

SUMMARY AND CONCLUSIONS

The study was activated by the awareness that there is very little information available concerning the effects of water exercise on the movements of Multiple Sclerosis patients. The effort and desire of the participants in the Washington State University program and the apparent changes in participant performance further stimulated the author to conduct the study.

The purposes of the study were (1) to determine changes in the linear range of motion of the shoulder, elbow, and wrist after a forty-five minute period of water activities and (2) to determine if the movement became more effective.

The test used was an overhand throw with a thirteen inch ball. The subjects were allowed practice throws before the pre-water tests. The two females had two pre and two post tests while the male had one of each.

The subjects were filmed with a Lo Cam Camera immediately preceding and following their normal aquatic programs.

A preliminary analysis using film tracings of the ball from the beginning of the power phase through the ball's flight was done (1) to determine if there were changes in ball velocity and (2) to determine the average force of the throw. Velocity and average force were determined by measuring vertical and horizontal displacements during the power phase and during the flight of the ball. The velocity

and average force were computed using the standard motion formulas. The film was digitized using a Graphic Tablet and computations were done on a Hewlett Packard 25 Calculator.

Findings⁽¹⁾

1. Average Force During Power Phase: Subjects one and two increased the force which was applied to the ball. Subject three showed a decrease in applied force. The results showed that the average force increased by an average of .54 pounds (2.4035 Newtons) which was an eighteen per cent improvement.

2. In Flight Horizontal Ball Velocities: All subjects were able to throw the ball with greater horizontal velocity after having been in the water. The increase averaged 6.01 ft/s which was a thirty-nine per cent improvement.

3. Horizontal Shoulder Displacement: Subjects one and three showed a decrease in horizontal shoulder displacement while subject two showed an increase in this parameter. There was an average decrease of .36 inches which was six per cent.

4. Vertical Shoulder Displacement: Subjects one and two showed an increase in vertical shoulder displacement while subject three showed a decrease in this parameter. There was an average increase of .29 inches which was 4.46 per cent.

5. Horizontal Elbow Displacement: Subjects one and three showed a decrease in horizontal elbow displacement while subject two showed an increase. There was an average increase of 1.95 inches which was 13.62 per cent.

6. Vertical Elbow Displacement: Subjects one and two showed an increase in vertical elbow displacement while subject three showed a decrease. There was an average increase of 2.27 inches which was 15.98 per cent.

7. Horizontal Wrist Displacement: Subjects two and three showed an increase in horizontal wrist displacement while subject one showed a decrease. There was an average increase of 1.62 inches which was 7.56 per cent.

8. Vertical Wrist Displacement: Subjects two and three showed an increase in horizontal wrist displacement while subject one showed a decrease. The average increase was 5.23 inches which was 24.86 per cent.

9. None of the changes were statistically significant at the $\alpha = .05$ level. However, the lack of statistical significance is not important to the individual who is able to move with more ease and efficiency through a greater range. The fact that the changes may be exceedingly minute does not deny individual joy.

Conclusion

It can be concluded that, except for the horizontal motion of the shoulder, range of motion force production, and horizontal ball velocity increased. In some instances where there were decreases in ROM, the decreases may have been due to the elimination of extraneous motions. Although statistically it was necessary to accept the null hypothesis, Multiple Sclerosis patients do not show a change in upper extremity range of motion and efficiency following water activity, the author believes that a larger study could prove the changes to be significant.

The specific reasons for the improvement cannot be attributed to the water activities alone. Other possible causes include Hawthorne Effect and water temperature.

Further research could provide more definitive reasons as to the benefits of water activities for Multiple Sclerosis patients.

(1) All statements concerning increases or decreases in performance compare the post throw to the pre throw.